F. K. BENDER · H. A. RAZA

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GEOLOGY OF PAKISTAN

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GEBRÜDER BORNTRAEGER

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edited by

F. K. Bender and H. A. Raza

1995

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D. Bannert, F. K. Bender, H. Bender, F. Grüneberg,
A. H. Kazmi, H. A. Raza and F. A. Shams

with contributions on nuclear fuels by

F. Barthel and H. Fohse

and on bituminous rocks by

H. Porth

With 140 figures and 38 tables in the text and on 10 fold-outs

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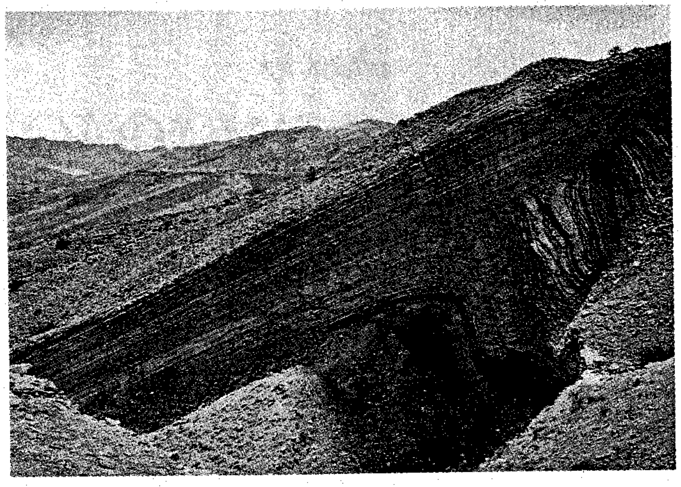
Authors' addresses:
Prof. Dr. F.K. BENDER, Oberhain 17, 34286 Spangenberg, Germany.
H.A. RAZA, Director General, Hydrocarbon Development Institute of Pakistan, 230, Nazimuddin Road F-7/4, Islamabad, Pakistan.
Dr. D. BANNERT, Dr. F. BARTHEL, Dr. H. BENDER, H. FOHSE, Bundesanstalt für Geowissenschaften und Rohstoffe, Postfach 51 01 53, 30631 Hannover, Germany.
Dr. F. GRÜNEBERG, Rhadenerweg 12, 30938 Burgwedel, Germany.
Dr. H. PORTH, Niedersächsisches Landesamt für Bodenforschung, Alfred-Benz-Haus, Stilleweg 2, 30655 Hannover, Germany.
A.H. KAZMI, Director General rtd., Geological Survey of Pakistan, FF 2 Block 59, Seaview Township, Defence Housing Authority, Karachi-75500, Pakistan.
Prof. Dr. F.A. SHAMS, Director, Center for Integrated Mountain Research, University of the Punjab, New Campus, Lahore-54590, Pakistan.



Ongoing small scale detachment tectonics within the Habib Rahi Limestone in the southeastern Sulaiman Range. The Habib Rahi Limestone of early Middle Eocene age is shown during the process of detachment with the development of the roof-thrust above the disturbed and vertical beds (dark colours). A floor thrust develops below the disturbed complex. The process is related to the mobilisation of underlying gypsum of the upper Ghazij Formation. Location: Dhaulian, north of Thak, along the eastern slope of the Sulaiman Range; 30° 33'N / 70° 12'E. The view is to the south. Photo: D. BANNERT.

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Foreword, Acknowledgements

Pakistan covers a land area of 796,096 km² between the latitudes 24°N to 37°N and the longitudes 61°E to 76°E. This region was the scene of a geodynamic evolution of particular complexity. The structural framework is the result of the collision and coalescence of three crustal plates: the Arabian Plate in the southwest, the Eurasian Plate in the northwest and north, and the Indo-Pakistan Plate in the southeast. The Pakistan parts of the Himalayas, Pamir, Hindukush and Karakorum belong to the highest elevated mountain chains on earth.

Plate collision, coalescence, orogeny and volcanism played an important role in the development of a great variety of natural resources. Different sedimentary basins were formed in the vast Indus Basin and in the offshore region, as well as in Baluchistan. Their palaeogeographic, stratigraphic and structural evolution provided the conditions for extensive energy and mineral resources, which have not yet been fully explored.

The complex geological features, the presence of a multitude of energy resources, of metallic and non-metallic commodities, of surface and groundwater and of a great variety of soils have attracted geoscientists since the middle of the 19th century when systematic geologic research and studies on prospection and exploration commenced.

An inventory of the water resources and modern hydrogeological exploration have substantially increased the knowledge of this vital commodity. The same applies to the soils of Pakistan: soil mapping, pedological research and the compilation of soil utilization maps have added considerably to the information on this natural resource.

Geologic research was intensified when Pakistan came into existence in 1947. Its importance for the development of the young nation was recognized in the following years by the establishment of important organizations including the Geological Survey of Pakistan, the Hydrocarbon Development Institute, the Centre for Integrated Mountain Research, institutes dealing with surface water, groundwater and soils, and geoscientific institutes in the universities of the country. During the past four decades, geoscientific research accelerated. National projects and international cooperation aimed at a better understanding of the geology and of the origin, pattern of distribution and efficient utilization of the natural resources. All these endeavours led to an ever-increasing wealth of information and data.

This volume of the Series "Contributions to the Regional Geology of the Earth" attempts to synthesize the present state of geoscientific research, information and interpretation. Naturally, such a synthesis is bound to be sketchy and incomplete; large areas, particularly in the north and west of Pakistan, are geologically not well known. The data on the deep subsurface geology are mainly restricted to areas of hydrocarbon exploration. Nevertheless, it appears to be worthwhile to sort out and compile the known facts and present interpretations for a synthesis. Such a synoptic overview might be helpful for future research on special and on regional questions. It also might help to identify gaps in the information and to identify targets for future endeavours.

All manuscripts of this volume were received in summer and autumn 1993.

The publication of this volume would have been impossible without the help of several institutions: The Federal Institute for Geoscience and Natural Resources, Hannover, Federal Republic of Germany; the Hydrocarbon Development Institute of Pakistan, Islamabad; the Geological Survey of Pakistan, Quetta; the Institute of Geology, Punjab University, Lahore; the Gem Corporation, Peshawar; the Water and Power Authority, Directorate General of Hydrogeology, Lahore, and the Soil Survey of Pakistan, Lahore. The authors wish to express their sincere thanks for the cooperation received from these institutes. The authors would like to especially thank Dr. JOHN A. REINEMUND, former chief of the office of International Geology of the USGS, Reston, Virginia, for his voluminous editorial work and profound geoscientific advice. Generous assistance was rendered by the Consul-General of the Islamic Republic of Pakistan in the Federal Republic of Germany, Dr. H. SCHNAPKA, Düsseldorf. Our appreciation and gratitude are due to the publisher Gebrüder Borntraeger, Dr. E. NÄGELE, Stuttgart, for patience and cooperation during the long preparation and for the generous form and layout of this volume.

F. K. BENDER

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1. General introduction

(HILAL A. RAZA and FRIEDRICH K. BENDER)

1.1 Area and population

Pakistan is located in the west of the South Asian Subcontinent. It stretches from 24°N to 37°N latitude and from 61°E to 76°E longitude (Fig. 1.1). The total land area of Pakistan is 796,096 km². The northeast to southwest extent of the country is about 1,700 km, and its east-west width is approximately 1,000 km. In the north and west, nearly 60 % of the land area is mountainous terrain and incised tableland topography. The remaining area consists of alluvial plains of the Indus River and its tributaries. The offshore Exclusive Economic Zone covers 231,674 km² in the Arabian Sea.

Pakistan is bordered in the east by India, in the north by Afghanistan and China, in the west by Afghanistan and Iran, and in the south by the Arabian Sea. The area of Jammu and Kashmir in the northeast is a disputed territory. China is linked to Pakistan via the famous silk route which is now an all weather road called the Karakorum Highway. The legendary Khyber Pass connects Afghanistan with Pakistan in the northwest. Rail and road links are maintained with Iran via Zahidan. There are several other passes dissecting the mountainous terrain in the north and west, providing traditional land routes to China, Afghanistan and Iran. The eastern border with India is also connected at a number of places by roads and railways. Karachi represents the main

Table 1.1. Population, size of areas, persons/km².

Province/Areas	Population	Area (km²)	Persons/km²
Total	84,253,644	796,096	106
Islamabad (Federal Capital)	340,286	906	376
Federally Administered Tribal and Northern Areas	2,198,547	27,220	81
Punjab	47,292,441	205,344	230
Sindh	19,028,666	140,914	135
North West Frontier Province	11,061,328	74,521	148
Baluchistan	4,332,376	347,190	12

(Source: Pakistan Statistical Year Book 1988)

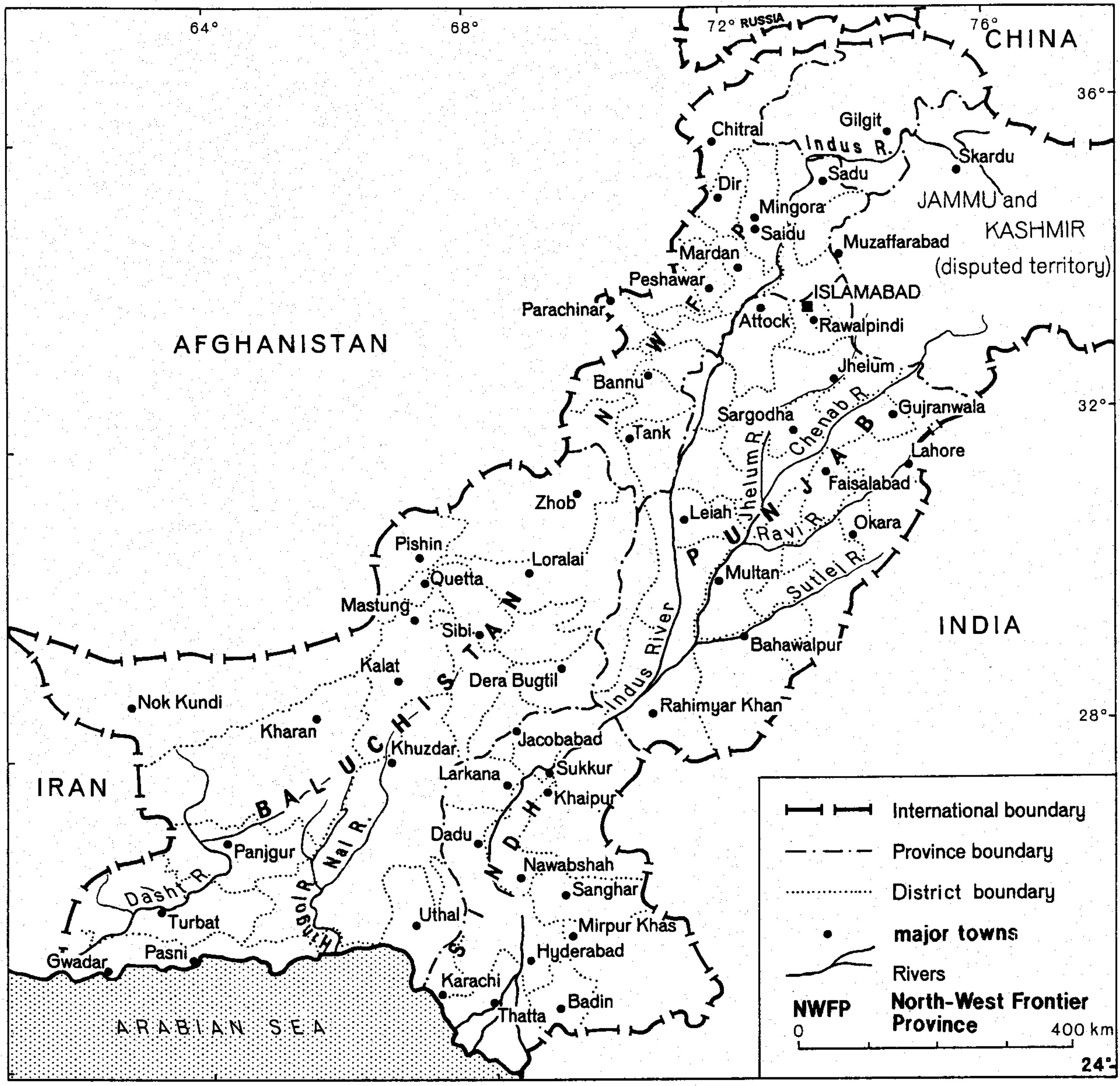


Fig. 1.1. Situation map of Pakistan showing Provinces, Districts, major rivers and towns. Simplified after physiographic maps on scale 1 : 3,000,000, Pakistan North and Pakistan South (by permission of Survey of Pakistan, Rawalpindi).

sea port; international air connections are available through mainly Karachi, Islamabad, Lahore and Quetta airports.

The Islamic Republic of Pakistan is a federation with its capital at Islamabad. The country is divided into four provinces (from south to north): Sindh, Baluchistan, Punjab and the North West Frontier Province (N W F P) with their respective provincial capitals at Karachi, Quetta, Lahore and Peshawar. The Federal Government also administratively controls two frontier areas, the Federally Administered Tribal Areas (F A T A) in the northwest, and the Federally Administered Northern Areas (F A N A) situated in the northernmost part of the Himalayas.

The population according to 1981 census was 84.25 million (Table 1.1).

1.2 Physiographic units

A great diversity of landforms characterizes the physiography, ranging from coastal beaches through fertile plains and sandy deserts to mountain belts. From south to north these belts are as follows (Fig. 1.2, fold-out):

- The West Pakistan Foldbelt or Western Mountains;
- the Baluchistan Highland;
- the Lower (Lesser) Himalayas, The Great (Higher) Himalayas and the Trans-Himalayas;
- the southern and northern Hindukush, and parts of the Pamirs (Fig. 1.2, fold-out).

The **Himalayas** stretch from the Hindukush in the west to the upper reaches of the Brahmaputra in the east for nearly 3,000 km, the western part of which lies in Pakistan. In Pakistan they can be divided longitudinally into four parallel zones following the northeast-trend (Hindukush), the ENE-east-trend (Pamirs) and the southeast-trend of the Himalayan arc (Fig. 2.3).

The **Siwalik Foot Hills** form the southernmost Himalayan zone. They start from the northern edge of the Potwar Plateau in the west and continue all along the length of Himalayan Range, covering the southern part of the Murree and Hazara areas including the Pabbi Hills in the east. This zone with altitudes generally ranging between 600 m – 900 m above sea level is about 10 km – 50 km wide. The foot hills form a broadly undulating landscape.

The **Lesser Himalayas** lie to the north of the Siwalik Foot Hills and include, among others, such ranges as Murree, Hazara, and Attock-Cherat. This zone is about 65 km – 80 km wide and includes mountains having altitudes between 1,500 m and 3,000 m ab. s. l.; they are of comparatively gentle and mature topography, but with deeply dissected valleys.

The **Great Himalayas** begin about 200 km – 250 km north of the edge of the Indus Plain and include the ranges of northern Swat, Kohistan and Kaghan, and the Pir Panjal Range in Kashmir. They show perpetually snow-capped peaks having an average altitude of 6,000 m ab. s. l., with extremely rugged and immature physiography. The Nanga Parbat (8,128 m) is located here.

The **Trans-Himalayas** are about 40 km wide in Pakistan, with an average height of about 6,000 m. They include the northern Hindukush, the Deosai and Laskar Mountains and the Karakorum Range which remain snowbound for the most part of the year. Six peaks of the Karakorum with altitudes close to, or more than, 8,000 m include the second highest mountain in the world (K-2; 8,611 m), the Gasherbrum (8,068 m), the Broad Peak (8,047 m), the Distaghel Sar (7,884 m), the Masherbrum (7,821 m) and the Rakaposhi (7,790 m). The Karakorum Range forms the main watershed between Central and South Asia. It also is the region of large glaciers, like the Batura (55 km length), Hispar (60 km), Biafo (50 km), Baltoro (55 km) and Siachen (75 km).

The **Western Mountains** (parts of them form the West Pakistan Foldbelt) include the southern Hindukush and the Koh-i-Sufaid, and the Salt, Sulaiman and Kirthar Ranges. The southwest-trending Hindukush branches off from the ENE-east-oriented Pamirs (Fig. 2.3). Altogether, the Hindukush is nearly 1,600 km long and 300 km wide and forms one of the great watersheds of Central Asia. Three minor ranges run from the Hindukush southwards into Chitral, Swat and Dir Districts. The altitudes of the

Hindukush range from 2,400 m – 4,500 m with the highest peak Tirich Mir, 7,692 m, in northern Chitral. Southwards, the altitudes decrease to 1,300 m – 1,500 m in the Mohmand and Malakand Agencies.

The **Koh-i-Sufaid Range** represents the southern continuation of the Hindukush south of the Kabul River, streching west with an average height of 3,600 m. Outliers in the Kohat and adjoining areas reach an average altitude of 900 m. Between the Kurram and Gomal Rivers lies the area of the Waziristan Hills. Here, Shoedar and Pirgul Peaks are the highest mountains, with altitudes above 3,500 m. The Wana Plateau to the south is a fertile cultivated area; the Tochi River traverses the central part of these hills.

The **Potwar Plateau** east of the Koh-i-Sufaid Range is a flat to gently undulating area between the Siwalik Foot Hills to the north and the Salt Range to the south, with altitudes ranging between 300 m and 600 m. It is drained by the Soan River flowing east to west.

The **Salt Range** is located at the southern margin of the Potwar Plateau. It extends from Jogi Tilla Hills and Bakrala Ridges westward to Kalabagh where it crosses the Indus River and continues into the Trans-Indus Salt Range. The average height is about 670 m, but near Sakesar it rises up to 1,422 m. The Salt Range is a feature of particular geological interest for its exposures of Precambrian through Quaternary sediments.

The **Sulaiman Range** trends south in an arcuate form from the Gomal River to Quetta, with the highest mountain near Quetta (Takht-i-Sulaiman; 3,375 m) at the southern end of the Sulaiman Range. The area of greatest curvature of mountains is occupied by the Loralai and Marri Bugti Hills ("Loralai Lobe"). The Pishin-Zhob and Quetta Valleys form large depressions near the southern limit of the Sulaiman Range.

The **Kirthar Range** is a south-trending mountain belt which attains an altitude of about 2,000 m, consisting of several parallel ridges, namely Mor, Pab, Khudo, Bhit, Badhra and Lakhi Ranges. It extends from south of Quetta to Cape Monze near Karachi and continues off-shore, passing into the Murray Ridge (Fig. 5.1). The highest point in the Kirthar Range is Mt. Zardac (2,265 m).

The **Baluchistan Plateau,** with an average altitude of about 600 m, is seperated from the Indus Plain in the east by the Sulaiman-Kirthar Ranges, and from Afghanistan in the west by the Chagai Hills. There are two low lying flat areas, namely the Dalbandin Depression and the Kharan Platform. A large part of the Plateau is occupied by deserts; a marked feature is the inland drainage resulting in the formation of salt playas like Hamun-i-Mashkel, which is some 87 km long and 35 km wide. The Dalbandin Depression and the Kharan Platform are intervened by the Ras Koh Range. Hills in the north of the Baluchistan Plateau consist partly of prominent Quaternary to sub-Recent volcanoes (e.g. Koh-i-Sultan). The area south of the Kharan Platform is occupied by the Siahan, Central Makran and Coastal Makran Ranges. Large mud flats are found in the coastal plains or in valleys bounded by ridges. Many mud volcanoes are observed in the southern Makran area.

The **Indus Plain** is drained by the Indus River and its tributaries, the Sutlej, Ravi, Chenab and Jhelum Rivers. It is the western part of the Indo-Gangetic-Brahmaputra alluvial plains to the south of the Himalayan Ranges. It covers an area of 292,700 km^2 in Pakistan and is the backbone of the agricultural economy of the country. The rivers have been experiencing floods, for example in 1947, 1958, 1973 and 1988, often rising as high as 7 m. The northern half of the Indus Plain is known as the Punjab (= five rivers) Plain.

It has an altitude of about 300 m ab. s. l. and is largely occupied by the unconsolidated deposits of the five rivers. The area between two rivers is locally known as a *doab*. The Punjab Plain is, therefore, divided into four large *doabs*: The Bari, Rechna, Chaj and Sindh Sagar *doabs*.

Beyond the irrigation limits of the Sutlej River in the south, the plain is covered by the Cholistan Desert, stretching in Pakistan over an area of about 15,000 km² and extending south and east into India. The Indus Plain extends into the Sindh Province (Sindh Plain) which, like the Punjab Plain, has been partly formed by the sediments of changing courses of meandering ancient rivers. The central Sindh Plain, between the left bank of the Indus River and the Thar Desert, forms a level alluvial plain; in the east, it merges with the desert where the landscape is dominated by sand dunes. Near Thatta, the distributaries of the Indus River begin to spread out across the deltaic flood plain into the sea. A coastal strip, 8 km to 40 km wide, is flooded at high tide and contains some mangrove swamps.

Along the edge of the Indian Shield, Precambrian rocks are exposed forming pronounced hills within the Quaternary sediments of the plains, for example the Kirana, Shah Kot, Chiniot and Sangla Hills in Sargodha, Punjab, and the Karunjhar Hills in Nagar Parkar, Sindh.

1.3 Climate and vegetation

Pakistan has a continental type of climate although the country lies on the western margin of the monsoon region. The Himalayas and the Western Mountain Ranges play an important role in the climatic variation of the region. Climatograms (Fig. 1.3) show the temperature and rainfall variations at some selected stations representing various climatic zones. The contours of the mean annual rainfall are shown on Fig. 1.4.

There are four distinct seasons (see also Tables 1.2, 1.3):

Table 1.2. Mean annual temperature (°C).

	Quetta	Rawalpindi Islamabad	Peshawar	Lahore	Multan	Jacobabad	Hyderabad	Karachi
m ab. s. l.:	1589	511	359	214	123	56	30	22
	Mean of Maximum							
1976	23.9	27.6	29.6	30.3	32.0	33.5	33.7	30.9
1978	24.2	28.6	29.7	31.0	32.6	33.4	33.9	31.4
1980	25.0	29.0	29.4	31.1	33.4	34.4	34.9	31.6
1982	22.9	27.9	29.0	29.9	35.0	33.1	34.0	31.9
1984	25.8	29.1	30.7	31.1	32.9	34.3	33.9	31.6
1985	25.3	29.8	30.5	31.7	33.3	34.4	34.5	32.1
1986	23.9	28.1	29.5	32.1	30.7	33.4	34.5	31.7
1987	25.7	29.7	30.5	33.1	31.9	34.7	35.9	32.6

Table 1.2. Continued.

	Quetta	Rawalpindi Islamabad	Peshawar	Lahore	Multan	Jacobabad	Hydera-bad	Karachi
m ab. s. l.:	1589	511	359	214	123	56	30	22
	Mean of Minimum							
1976	6.6	13.0	15.6	18.5	17.3	20.3	21.3	18.6
1978	6.8	14.7	16.3	18.3	17.7	20.3	21.2	20.7
1980	7.3	14.4	15.3	18.1	18.5	20.0	21.5	21.1
1982	7.3	13.9	15.5	17.2	18.8	19.9	21.3	20.6
1984	8.1	13.7	15.5	18.0	17.5	18.9	19.2	19.6
1985	7.6	14.5	16.3	18.3	17.8	19.5	20.8	20.0
1986	8.6	12.3	15.5	17.6	17.7	19.3	20.9	19.8
1987	7.7	14.2	15.8	18.3	18.4	19.5	21.5	20.4

(Source: Pakistan Statistical Year Book 1988)

- **Winter season** from December to March: influenced by the frequent passing of western disturbances originating over the Mediterranean Sea and advancing through the Arabian Peninsula, Iran and Afghanistan to Pakistan; a brief spring is witnessed in February to March in some areas.
- **Summer season** from April to June: charcterized by dry weather and high temperature with the highest in May and June.
- **Rainy season** from July to September: by the end of hot and dry summer season, a thermal low called "Indus Low" establishes over a large area of the Indus Plain, together with a marked change in the wind direction and the onset of the southwest monsoon over the South Asian Subcontinent.
- **Autumn season** from October to November: period between the retreat of monsoon and onset of winter, with generally pleasant weather but rise in temperature in the coastal belt.

The following three climatic zones might be differentiated:

The mountainous region shows a considerable diversity with cold winters, frequent frost and snow falls, and mild summers. In the high mountainous areas, maximum temperature of 15 °C and minimum touching - 10 °C have been recorded. The Lesser Himalayas are the most humid part of the country, receiving an annual precipitation of about 180 mm as observed at Murree. Winter rains and occasional snowfall occur during January to March. Towards north in the Himalayas, the climate becomes steadily drier to arid.

The Indus Plain has a continental climate with significantly high temperature in summer (mean June temperature 38 °C, extreme maximum above 50 °C) and moderate weather in winter (mean January temperature 24 °C).

The coastal region does not exhibit extreme high temperature because of high air humidity. The seasons are more moderate than in the Plain, the temperature in winter being only 6 °C to 10 °C lower than in summer. In Karachi, the mean June maximum is 35 °C.

A number of climatograms, based on the system used by WALTER (1955), are shown in Fig. 1.3; in these diagrams the mean monthly temperatures and the mean monthly precipitation (a 30 year average in each case) are compared with each other.

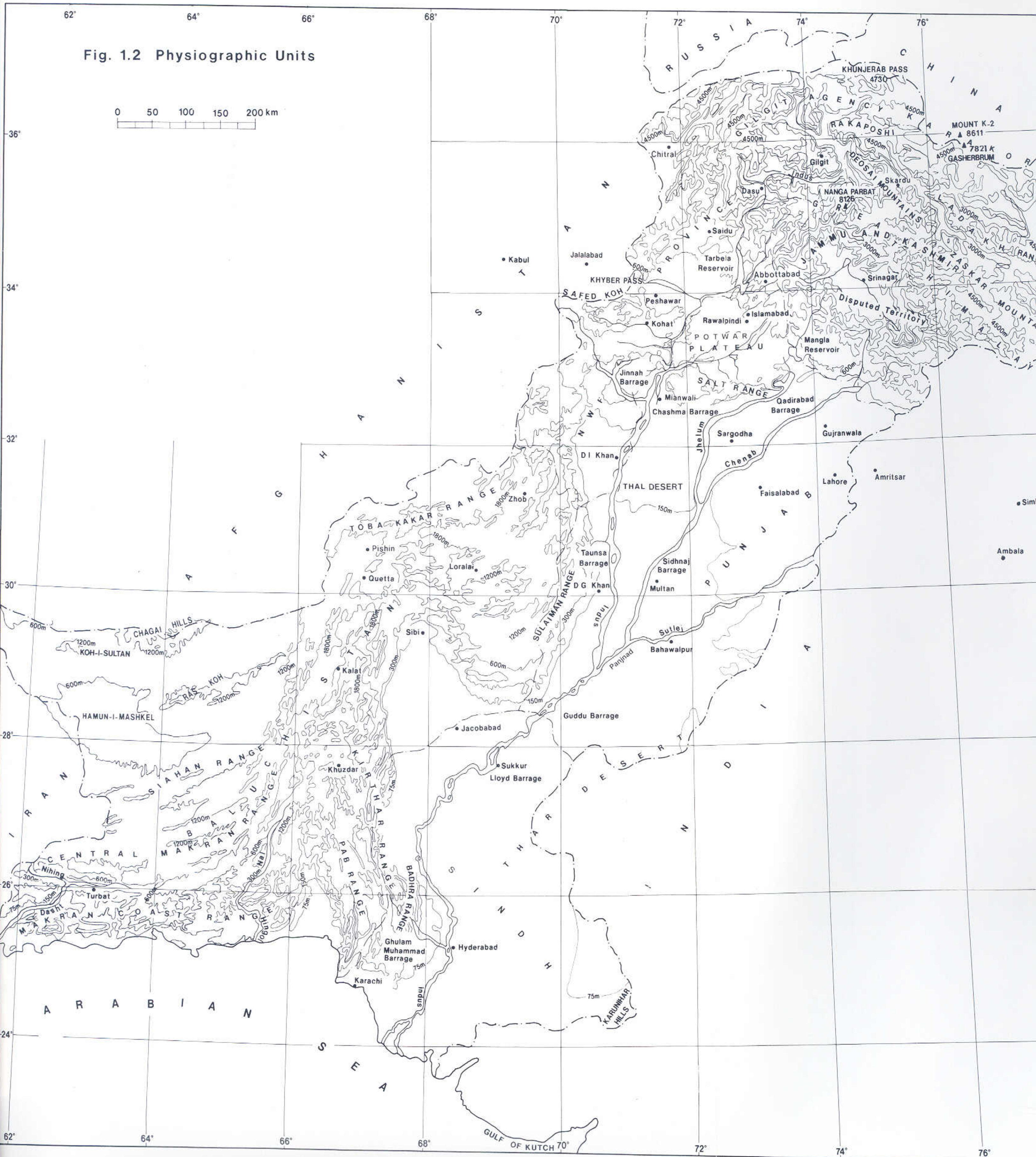


Fig. 1.2. Physiographic Units. Simplified after physiographic maps on scale 1 : 3 mio. Pakistan North and Pakistan South (by permission of Survey of Pakistan, Rawal

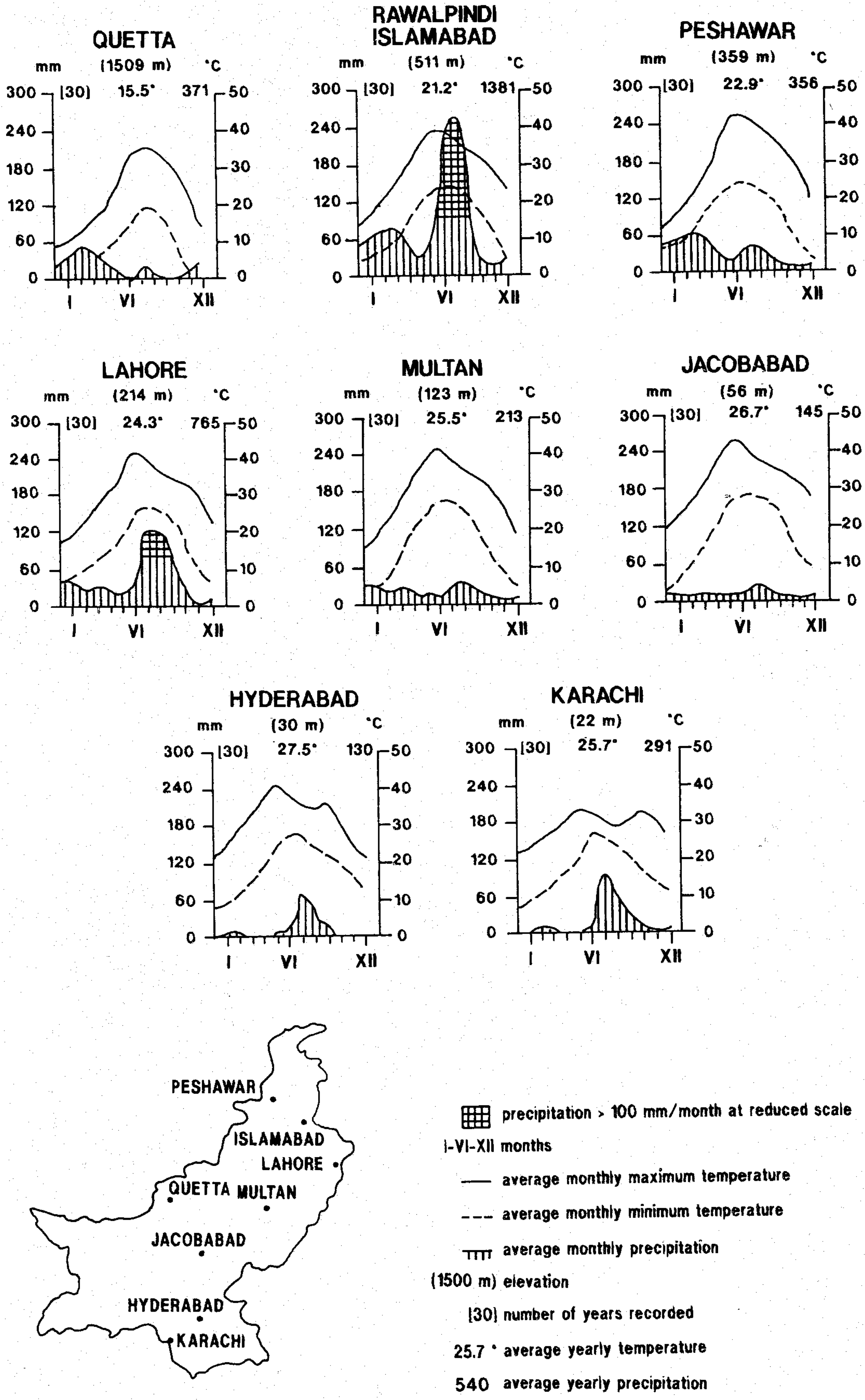


Fig. 1.3. Climatograms after the system of WALTER (1955).

Table 1.3. Mean annual rainfall (mm).

	Quetta	Rawalpindi Islamabad	Peshawar	Lahore	Multan	Jacobabad	Hyderabad	Karachi
m ab. s. l.:	1589	511	359	214	123	56	30	22
1976	322	1,667	625	1,149	427	188	335	406
1978	317	1,430	498	710	309	338	416	387
1980	255	1,084	371	1,014	149	14	119	195
1982	949	1,632	323	596	166	84	54	162
1984	115	1,143	524	702	106	202	206	270
1985	257	1,124	341	746	158	183	116	155
1986	244	937	416	612	219	84	178	92
1987	156	859	343	490	108	38	490	–

(Source: Pakistan Statistical Year Book 1988)

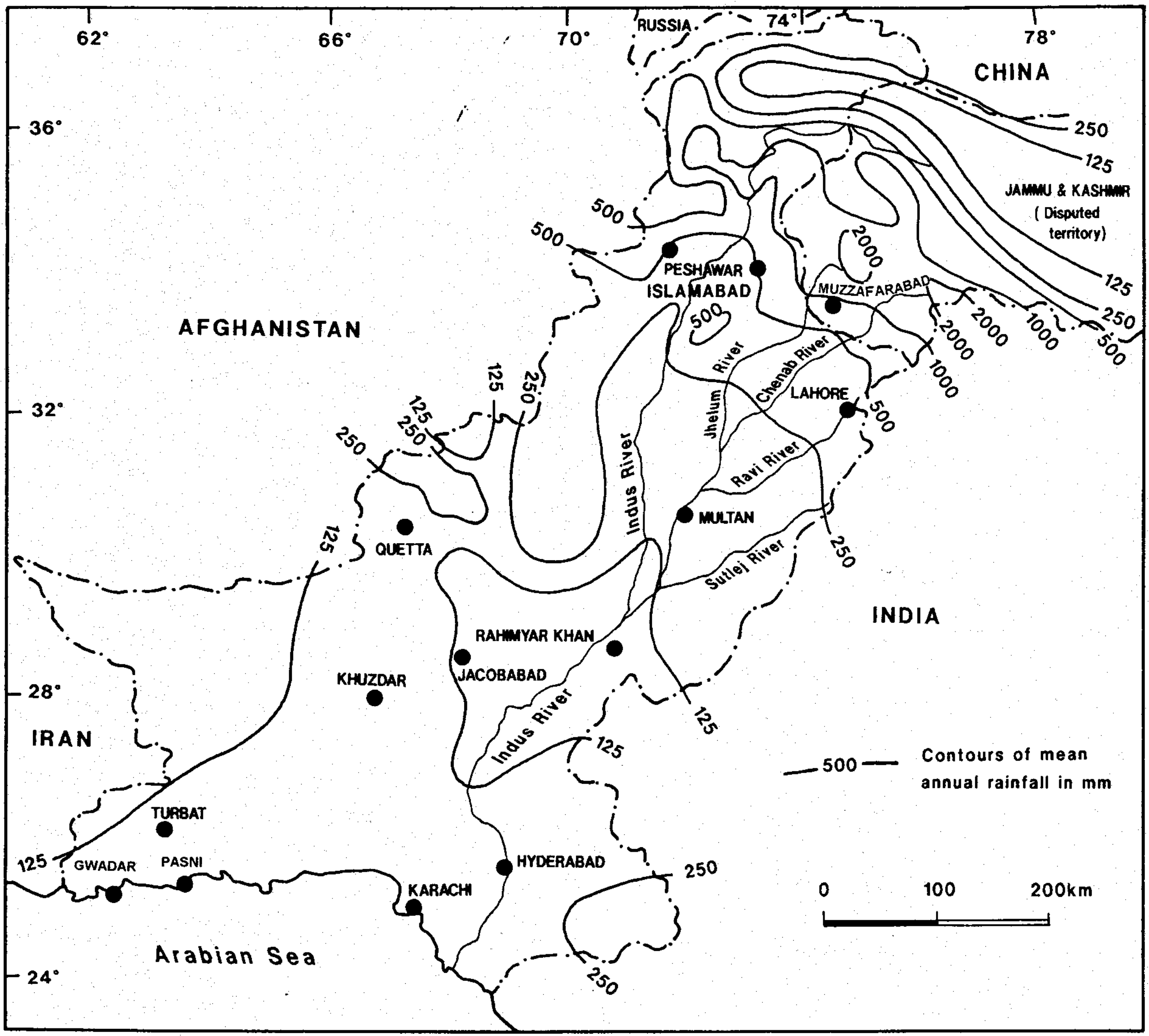


Fig. 1.4. Contours of the mean annual rainfall (base data after Pakistan Statistical Year Book 1988).

Due to the diverse climatic conditions, a wide range of **vegetation** exists, from cacti and shrubs in dry-hot regions to junipers, pines and cedrus in mild-wet areas. Areas lying between 3,400 m – 4,000 m altitude ab. s. l. bear alpine vegetation such as Juniper, Rhododendron, and *Ephedra*. There is also a rich herbaceous growth including a variety of palatable grasses. The regions of Baluchistan, North West Frontier Province, and the northern mountains lying between 1,800 m – 3,400 m altitude bear a vegetation of dry temperate forests, particulary *Juniperus macroploda* and *Pinus geadiana*. Below this zone, the main vegetation pertains to dry temperate semi-evergreen forests of *Olea, Pistacia, Quercus* and *Ilex* types. The Salt Range, Kala Chitta, Sulaiman and Kirthar Ranges are characterized by dry subtropical semi-evergreen shrubs. Typical plant species are *Olea cuspitata* occupying cooler locations and *Acacia modesta* flourishing on warmer sites.

There is a marked deficiency of tree cover; only 3.5 % of the total country is forested.

1.4 History of geological research

The recorded history of geological research dates back to the middle of the 19th century when the first geological survey was undertaken by LAMESSURIER (1844) for antimony and lead in Baluchistan. With the establishment of the Geological Survey of India in 1851, systematic geological studies commenced in selected areas. The pioneering works in the Salt Range and Hazara by FLEMING (1852), WYNNE (1875), LYDEKKER (1878) and MIDDLEMISS (1896) formed the basis for further research in these areas. VICARY (1847) carried out reconnaissance geological surveys of parts of Sindh which paved the way for investigations by BLANFORD (1879). During the course of geological mapping, BLANFORD found the coal deposits of Lakhra in Sindh (1867) and of Mach and Sharigh in Baluchistan (1882). The first oil well was drilled by the Government in 1866 at an oil seepage at Kundal near Mianwali, and a general appraisal of oil occurrences in Punjab was made by LYMAN (1872). Reconnaissance geological work was carried out in selected areas of Pakistan during the period from 1870 to 1900, by KING (1889), OLDHAM (1890 a), LATOUCHE (1894), NOETLING (1894) and others. With the beginning of the 20th century, more attention was given to mineral and oil exploration in addition to basic geological studies of the unexplored areas. VREDENBURG published the results of his comprehensive research work all over Baluchistan in 1910. Investigations during this period included studies of Tertiary and post-Tertiary sequences of Baluchistan (PILGRIM 1908), of salt deposits in the Salt Range, on the geology of the Kohat area (CHRISTIE 1914, SAHNI 1946), and on the geology of Potwar and adjoining regions (DAVIES 1930). The initial exploration for hydrocarbons gained momentum (PASCOE 1920); the efforts of the Attock Oil Company Ltd. led to the discovery of various oil fields. Geological investigations in the northern areas including Chitral, Gilgit and Kashmir began in the early 20th century; with contributions by HAYDEN (1915), WADIA (1919) and SONDHI (1942).

A regional geologic map was published by the Geological Survey of India in 1931. WADIA (1919), KRISHNAN (1949) and PASCOE (1950) authored volumes on the geology of the South Asian Subcontinent which still represent standard texts in the region.

At the time of the independence, only about 10 % to 15 % of the territory of Pakistan was geologically mapped at 1 inch to 4 miles (1 : 235,440) or smaller scales. Hunting Survey Corp. (1960) carried out aerial photography of the whole country on 1 : 40,000 scale, and prepared reconnaissance geological maps on 1 : 235,440 scale along with accompanying detailed reports for the major part of Baluchistan and Sindh provinces. Utilizing this information, systematic regional geological mapping on 1 : 50,000 scale was started by the Geological Survey of Pakistan in 1960; since then about 35 % of the country has been mapped geologically on this scale while ground gravity and magnetic coverage has also been of the same order. In 1964, a geological map on scale 1 : 2,000,000 was published (BAKR & JACKSON 1964). GEE's work on the Salt Range was published in 1981 in the form of geological maps on scale 1 : 50,000. Aeromagnetic surveys over 108,000 km^2 covering mineral bearing areas of Baluchistan and Sindh were carried out in 1975-76 (SPECTOR 1981). The information from more than 350 oil and gas exploratory and 500 development wells so far drilled represents a wealth of geological data for further research.

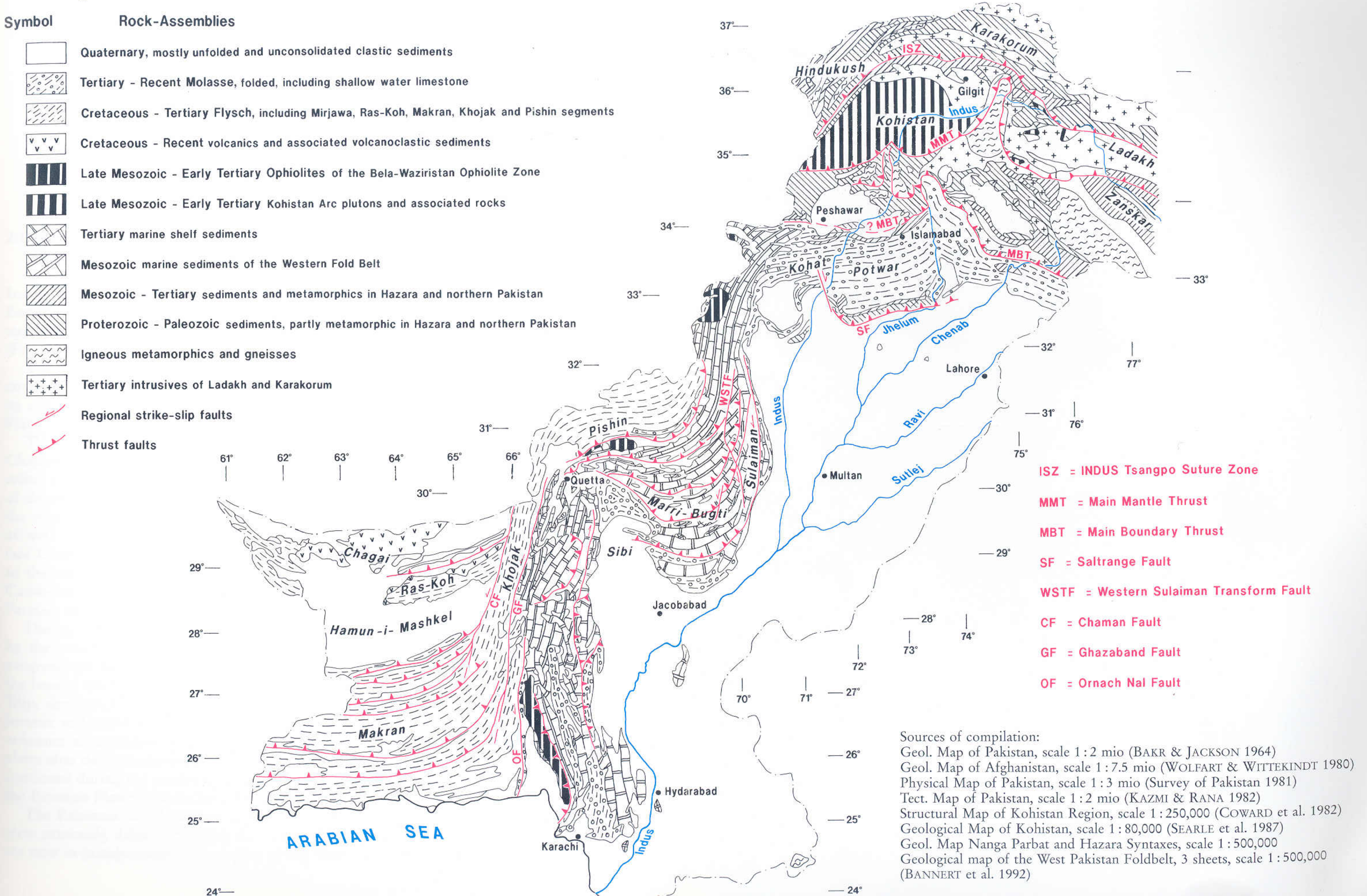
Some of the major contributions in the post-independence period relating to stratigraphy and geology include the works of KHAN (1950), GILL (1952), EAMES (1952), SCHINDEWOLF & SEILACHER (1955), HAQUE (1956), WILLIAMS (1959), DESIO (1959-1978), REHMAN (1963), TEICHERT (1964 a), LATIF (1964, 1970 a), KUMMEL (1966), DANILCHIK & SHAH (1967), FATMI (1968), STAUFFER (1968 a), VOSKRESENSKY et al. (1968 a, b), SHCHEGLOW (1969) and CALKINS et al. (1978). The 1960s and 1970s saw the initiation of several economic mineral surveys, the most prominent being Saindak copper porphyry (KHAN 1974), Dera Ghazi Khan uranium (MOGHAL 1974 b), marble (AHMED 1965); Khuzdar barite and Swat emerald (DAVIES 1962), Hazara phosphate (HASAN & GHAZNAVI 1980), and Khuzdar lead-zinc (GAUHAR 1969). Emphasis of geological research shifted to oil, gas and coal exploration leading to a number of important publications, for example, SHAH (1977), KAZMI & RANA (1982), KHAN & RAZA (1986), KHAN et al. (1986), RAZA & SHEIKH (1988), AHMED et al. (1987), RAZA et al. (1989, 1990). Recent major contributions have been the Hydrogeological Map on 1 : 200,000 scale (WAPDA & GOP 1989), and a book on gemstones of Pakistan (KAZMI & O'DONOGHUE 1990).

The development of plate tectonic concepts in the 1970s caused the initiation of integrated multidisciplinary geological research which was dominated by team work and joint research projects between several foreign and Pakistani research groups. Some noteworthy publications include FARAH & DEJONG (eds.; 1979), TALENT & MAWSON (1979), TAHIRKHELI (1980), MARUSSI (1980), GANSSER (1981), SHAMS (1983 a, b), Pakistani-Japanese Research Group (1985), LEGGETT & PLATT (1986), JOHNSON et al. (1986), LILLIE et al. (1987), and COWARD et al. (1988).

Many researchers were and are attracted by the Himalayas and the western mountains which form an ideal laboratory field for the study of structural deformation and processes of metamorphism of the continental and oceanic crust during collision orogeny. In recent years, a wealth of new information was published by, among many others, COWARD et al. (1982, 1986, 1987), TALENT et al. (1982), BURTMAN (1983), FARAH et al. (1984), MOLNAR (1986), SEARLE et al. (1987), BUTLER & PRIOR (1988 b), OWEN (1989), JAN, KHAN & HAMIDULLAH (eds.; 1989) and a publication on the structural development of the Western Foldbelt (BANNERT et al. 1992).

Fig. 2.1. Geological Map of Pakistan, Scale 1 : 7,500,00

complied by D. Bannert


Legend
Symbol
Rock-Assemblies
Quaternary, mostly unfolded and unconsolidated clastic sediments
Tertiary - Recent Molasse, folded, including shallow water limestone
Cretaceous - Tertiary Flysch, including Mirjawa, Ras-Koh, Makran, Khojak and Pishin segments
Cretaceous - Recent volcanics and associated volcanoclastic sediments
Late Mesozoic - Early Tertiary Ophiolites of the Bela-Waziristan Ophiolite Zone
Late Mesozoic - Early Tertiary Kohistan Arc plutons and associated rocks
Tertiary marine shelf sediments
Mesozoic marine sediments of the Western Fold Belt
Mesozoic - Tertiary sediments and metamorphics in Hazara and northern Pakistan
Proterozoic - Paleozoic sediments, partly metamorphic in Hazara and northern Pakistan
Igneous metamorphics and gneisses
Tertiary intrusives of Ladakh and Karakorum
Regional strike-slip faults
Thrust faults
ISZ = INDUS Tsangpo Suture Zone
MMT = Main Mantle Thrust
MBT = Main Boundary Thrust
SF = Saltrange Fault
WSTF = Western Sulaiman Transform Fault
CF = Chaman Fault
GF = Ghazaband Fault
OF = Ornach Nal Fault
Karakorum
Hindukush
Gilgit
Indus
Kohistan
ISZ
MMT
Ladakh
Zanskar
Peshawar
? MBT
Islamabad
MBT
Kohat
Potwar
SF
Jhelum
Chenab
Lahore
Ravi
Sutlej
Multan
Indus
WSTF
Sulaiman
Pishin
Quetta
Marri - Bugti
Sibi
Jacobabad
Chagai
Ras-Koh
Khojak
CF
GF
Hamun-i- Mashkel
Makran
OF
Hydarabad
Karachi
Indus
ARABIAN SEA
61°
62°
63°
64°
65°
66°
70°
71°
72°
73°
74°
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78°
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Sources of compilation:
Geol. Map of Pakistan, scale 1 : 2 mio (BAKR & JACKSON 1964)
Geol. Map of Afghanistan, scale 1 : 7.5 mio (WOLFART & WITTEKINDT 1980)
Physical Map of Pakistan, scale 1 : 3 mio (Survey of Pakistan 1981)
Tect. Map of Pakistan, scale 1 : 2 mio (KAZMI & RANA 1982)
Structural Map of Kohistan Region, scale 1 : 250,000 (COWARD et al. 1982)
Geological Map of Kohistan, scale 1 : 80,000 (SEARLE et al. 1987)
Geol. Map Nanga Parbat and Hazara Syntaxes, scale 1 : 500,000
Geological map of the West Pakistan Foldbelt, 3 sheets, scale 1 : 500,000 (BANNERT et al. 1992)

2. Geological framework

2.1 Introduction

(FRIEDRICH K. BENDER)

Inasmuch as Pakistan lies along the contact between the Indo-Pakistan and the Eurasian Plates it has had an exceptionally complex geologic history. The details of its stratigraphy, structure and geologic evolution are presented in the chapters that follow (Fig. 2.1; Geological Map, fold-out).

The **stratigraphic succession** in Pakistan (see Chapter 3) reflects the depositional environment of the Indo-Pakistan Plate and the volcanic events before, during and after its collision with the Eurasian Plate, as well as the ongoing accretion of the Arabian Plate.

The Precambrian metamorphic and igneous rock complex of the Indian Shield (see Chapter 5.1) is overlain by Precambrian, Paleozoic and Mesozoic sequences, which reflect the depositional conditions along the western edge of the Indian Shield. The area of deposition oscillated considerably during geological history. During the Paleozoic, the region of deposition was divided in large marine and, at times, terrestrial basins as well as intervening swells which received little or no accumulation of sediments (see Chapters 6, 7.1); the source of pelites and clastics was mainly the Indian Shield, to the east. Regional unconformities were developed between Late Proterozoic and Cambrian (Fig. 3.2), and at the base of the Permian sediments; Cambrian through Permian sediments were deposited widely in the Himalayas.

During the Mesozoic, the depositional pattern in the Indus Basin was influenced by the structural deformation of the area west of the Indian Shield, which became progressively more complex after the Cretaceous. A major unconformity developed at the base of the Jurassic (see Chapter 2.24). Late Cretaceous basaltic rocks, the Deccan Trap, developed in southeast Pakistan and the Panjal Trap in north Pakistan. Early Jurassic to Eocene, mainly marine, rock sequences including Jurassic/Early Cretaceous volcanics accumulated on, and at the margins of, the Indo-Pakistan Plate and microplates after the formation of the Neo-Tethys Ocean (see Chapter 6.2). The sedimentation continued during the northward drift of the Plates until the collision and suturing with the Eurasian Plate began in Late Cretaceous time.

The Paleozoic and Mesozoic sequences deposited west of the Indian Shield, which were extremely deformed during the northward migration of the Indo-Pakistan Plate, are now in juxtaposition in the region of the West Pakistan Foldbelt (see Chapter 2.23;

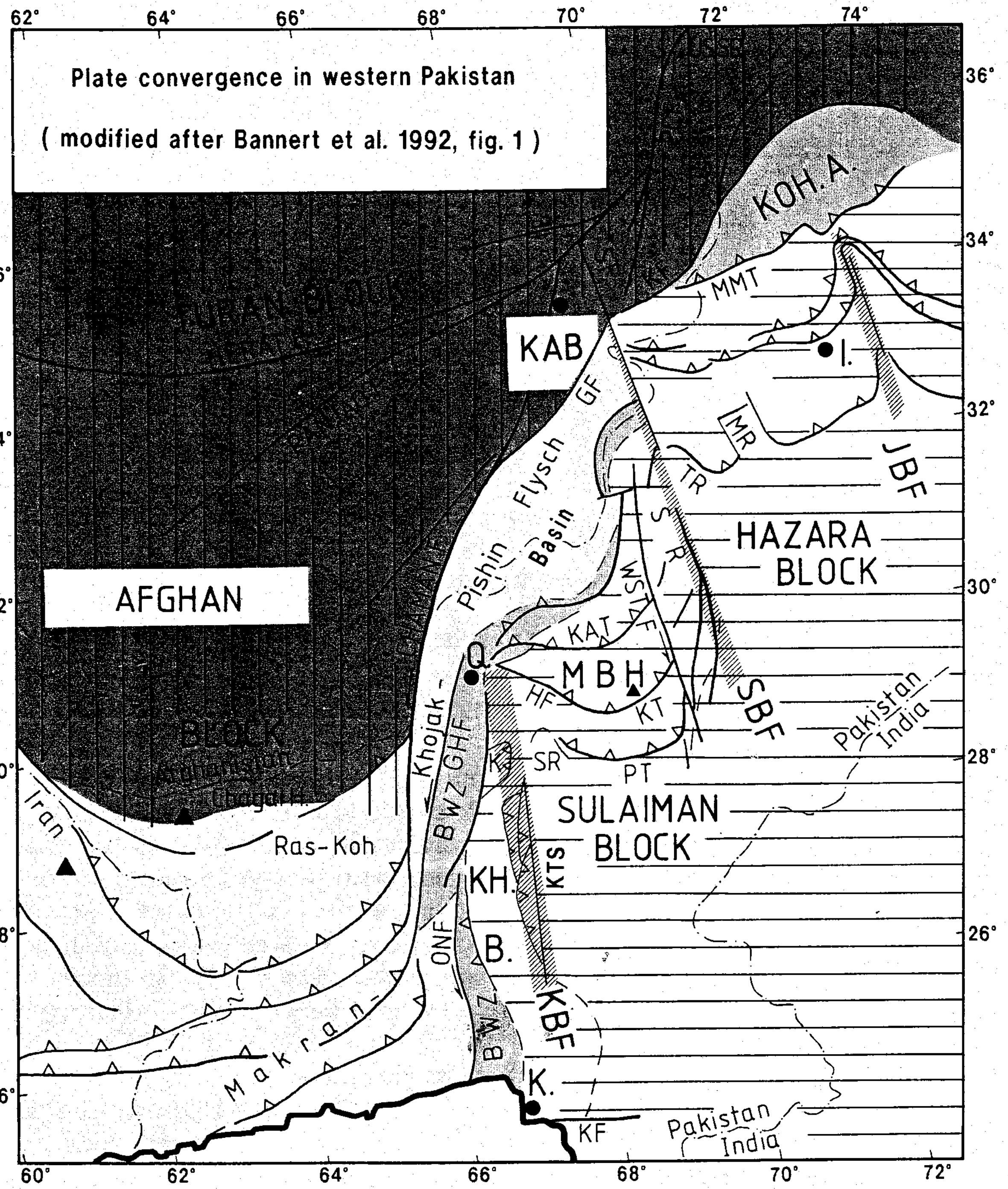


Fig. 2.2. Plate convergence in western Pakistan (modified after BANNERT et al. 1992, fig. 1). BWZ: Bela-Waziristan Ophiolite Zone; GF: Gardez Fault; GHF: Ghazaband Fault; HF: Harnai Fault; HERAT F.: Herat Fault; I: Islamabad; JBF: Jhelum Basement Fault; K: Kalat Plateau; K.: Karachi; KAB: Kabul Block and Kabul; KAT: Karahi Thrust; KBF: Kirthar Basement Fault; KF: Kumar Fault; KHB: Khuzdar Block; KOH.A.: Kohistan Island Arc Complex; KT: Karmari Thrust; KTS: Kirthar Thrust Sheets; KUF: Kutch Fault; MBH: Marri-Bugti Hills; MMT: Main Mantle Thrust; MR: Mianwali Re-entrant; ONF: Ornach-Nal Fault; PCF: Panjpir Fault; PT: Pirkoh Thrust; SBF: Sulaiman Basement Fault; SR: Sibi Re-entrant; SR: Sulaiman Range; SF: Sarobi Fault; TR: Tank Re-entrant; WSTF: Western Sulaiman Transform Fault.

Fig. 2.2) along with fragments of oceanic crust island arcs, and ophiolites. A regional unconformity appears at the base of the Paleocene.

Sediments of Late Eocene to Quaternary age were deposited during and after suturing. They consist dominantly of flysch- and molasse facies, and include Pliocene/Quaternary volcanics. Sources of the marine pelites and clastics in these deposits were the elevated and rising regions of the West Pakistan Foldbelt and the Himalayas. They were deformed progressively toward the north in the process of suturing and final phases of the collision. Close to the Neogene and younger fault zones, sequences of Quaternary age were also involved in the structural deformation.

The **structural framework** (see Chapter 5) which is dominantly the result of the collision, reflects the complicated pattern of competent and incompetent tectonic blocks as a whole, and of competent and incompetent rock sequences in particular, in the region west of the Indian Shield. In the southwestern part of Pakistan (see Chapters 2.25, 5.23, 5.24), the dominant structural features trend east in the Makran region and

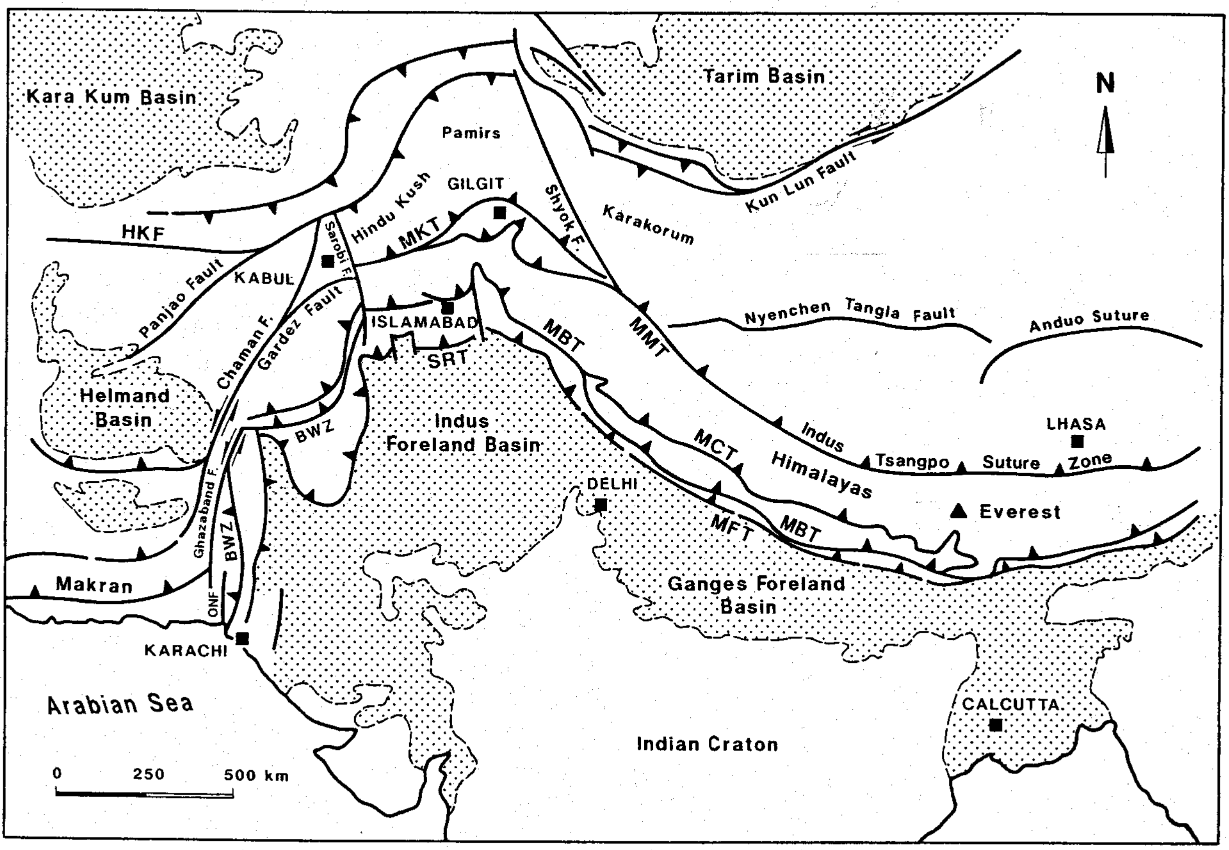


Fig. 2.3. Dominant structures of the West-Himalayas (compiled and simplified after Tahirkheli & Jan 1979, Gansser 1979, 1983, Tapponier et al. 1981, Searle et al. 1989, Cerveny 1989, Owen 1989). HKF: Herat-Hindu Kush Fault Zone; MMT: Main Mantle Thrust; MBT: Main Boundary Thrust; MFT: Main Frontier Thrust; BWZ: Bela-Waziristan Ophiolite Zone; MKT: Main Karakorum Thrust; MCT: Main Central Thrust; SRT: Salt Range Thrust; ONF: Ornal Nal Fault.

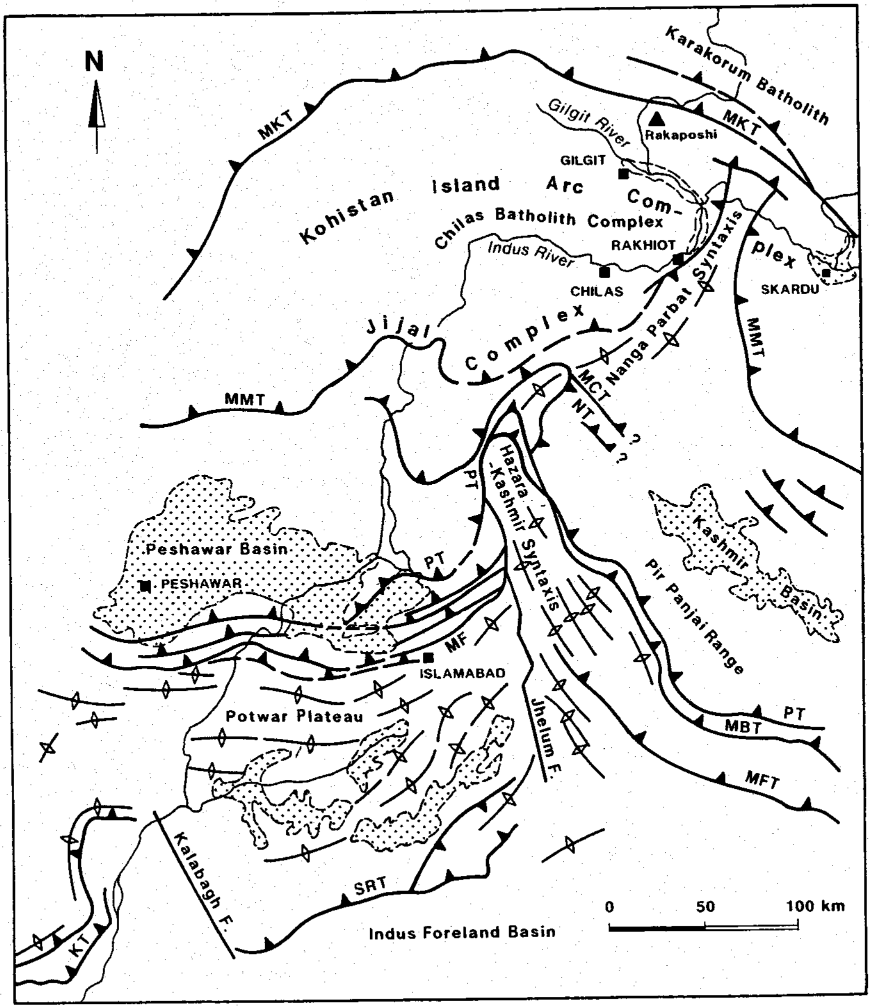
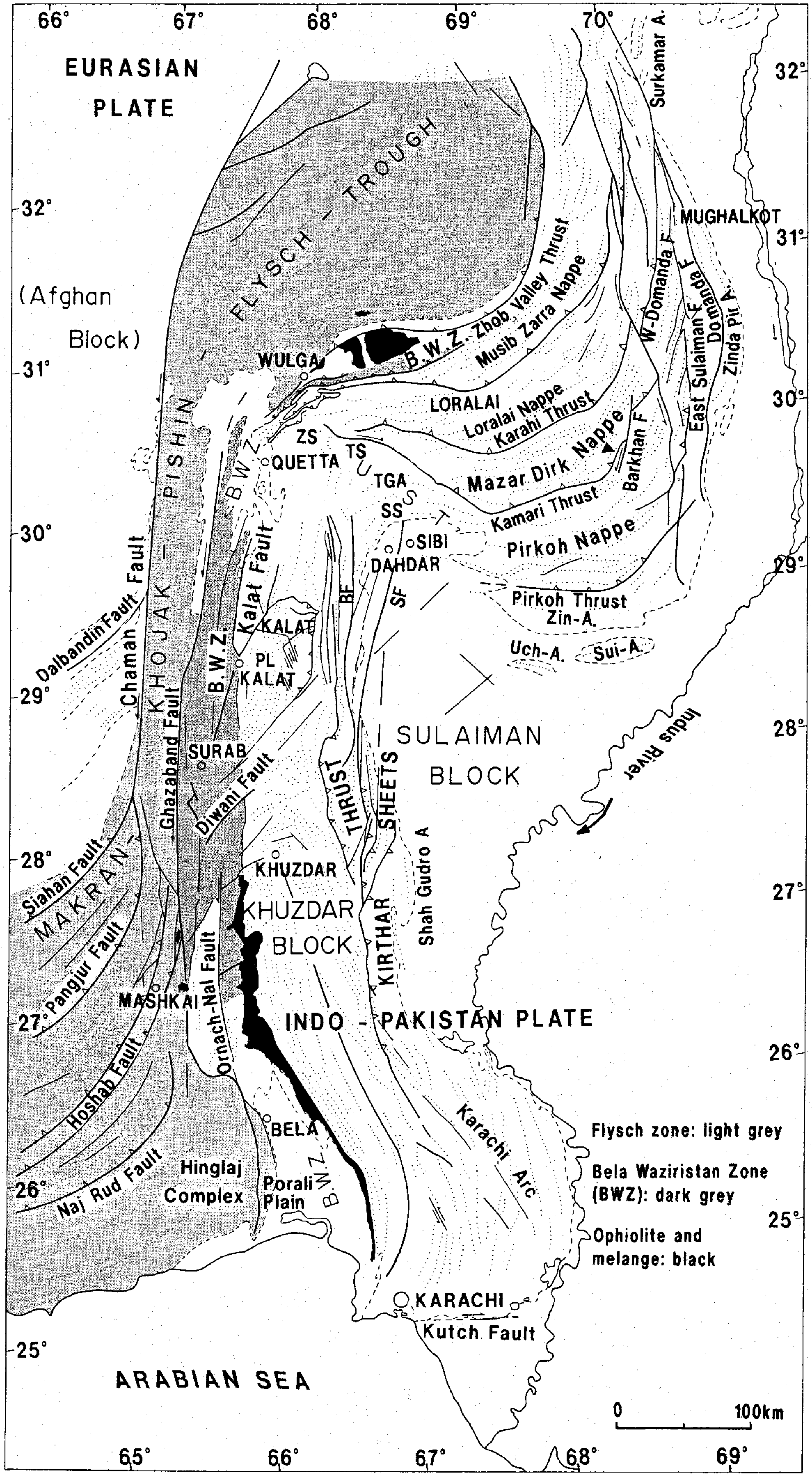


Fig. 2.4. Dominant structures of the Pakistan Himalayas (compiled and simplified after Tahirkheli & Jan 1979, Lillie et al. 1987, 1988, Bossart et al. 1988, Searle et al. 1989, Owen 1989, Treloar et al. 1989, Baig et al. 1989). AT: Alpurai Thrust; KT: Kisor Thrust; MBT: Main Boundary Thrust; MCT: Main Central Thrust; MF: Murree Fault; MFT: Main Frontal Thrust; MKT: Main Karakorum Thrust; MMT: Main Mantle Thrust; NT: Naram Thrust; PT: Panjal Thrust; SRT: Salt Range Thrust.

turn north in parallel with the West Pakistan Foldbelt (Fig. 2.4). Further to the north in approaching the Himalayas, they swing to the northeast before curving into the general ESE-direction of the Himalayas. The course of the tectonic elements is here marked by the Main Boundary Thrust (MBT), the Main Mantle Thrust (MMT), and the Main Karakorum Thrust (MKT; Figs. 2.3, 2.4).

Fig. 2.5. Dominant structures in the Makran-Khojak-Pishin and Sulaiman region (after Bannert et al. 1992, fig. 2). A: Anticline; BF: Bolan Fault; BWZ: Bela-Waziristan Ophiolite Zone; SF: Sanni Fault; SS: Sangan Syncline; TGA: Tor Ghar Anticline; TS: Timur Syncline; UST: Urak Sibi Trough; ZS: Zarghun Syncline.


66°
67°
68°
69°
70°
32°
31°
30°
29°
28°
27°
26°
25°
65°
66°
67°
68°
69°
EURASIAN
PLATE
FLYSCH - TROUGH
(Afghan
Block)
Surkamar A.
MUGHALKOT
WULGA
B.W.Z.
Zhob Valley Thrust
Musib Zarra Nappe
W-Domanda F.
East Sulaiman F.
Domanda F.
Zinda Pir A.
LORALAI
Loralai Nappe
Karahi Thrust
Barkhan F.
Mazar Dirk Nappe
ZS
TS
QUETTA
TGA
SS
Kamari Thrust
Pirkoh Nappe
SIBI
DAHDAR
Pirkoh Thrust
Zin-A.
Uch-A.
Sui-A.
BF
SF
PISHIN
KHOJAK
B.W.Z.
Chaman Fault
Dalbandin Fault
Kalat Fault
KALAT
PL
KALAT
Ghazaband Fault
SURAB
Diwani Fault
SULAIMAN
BLOCK
Indus River
THRUST
SHEETS
Shah Gudro A
KHUZDAR
KHUZDAR
BLOCK
KIRTHAR
Siahan Fault
MAKRAN
Panjgur Fault
MASHKAI
Ornach-Nal Fault
INDO - PAKISTAN PLATE
Hoshab Fault
BELA
Karachi Arc
Naj Rud Fault
Hinglaj
Complex
Porali
Plain
BWZ
KARACHI
Kutch Fault
ARABIAN SEA
0
100km
Flysch zone: light grey
Bela Waziristan Zone
(BWZ): dark grey
Ophiolite and
melange: black

The region of the West Pakistan Foldbelt along with the flysch segments (Fig. 2.5) displays (from south to north):
- a broad accretionary wedge, the Makran Flysch Segment, with the Chagai-Ras Koh area, characterized by east-trending, northward-directed thrusts, convex to the south;
- the Khojak Flysch Segment where the Makran thrusts turn to the north and grade into north-striking transform faults;
- the Pishin Flysch Segment with ENE trending, southeast to south-directed thrusts, also convex to the south.

The Pishin Segment ends in the north, in Afghanistan, at the Kabul Block of the Eurasian Plate and at major, NNW-striking transform faults.

With the Salt Range Thrust, the MBT, the MMT, the Kohistan Arc and the MKT, the dominant structures turn ENE before they swing into the regional ESE-strike of the Himalayas around the Nanga Parbat Syntaxis (Figs. 2.4, 2.6).

The MMT forms the suture between the main mass of the continental Indo-Pakistan Plate to the south and the Kohistan Island Arc Complex to the north (see Chapter 2.25). The extensive island-arc sequence of the Kohistan Arc is separated from the Karakorum micro-plate in the north by the MKT (Fig. 2.24).

In the Himalayas, within the ENE-east-ESE curvature of the tectonic frame, two conspicuous structural features interrupt the regional trend: the northwesterly oriented Hazara-Kahmir Syntaxis, and the northeasterly trending Nanga Parbat Syntaxis, the former bordered by the MBT, the latter by the MMT.

2.2 Principal geological divisions

In this chapter, the principal geological divisions are discussed, from south to north, as follows:
- Chagai and Ras Koh area (2.21),
- Makran-Khojak-Pishin Flysch Zone (2.22),
- West Pakistan Foldbelt (2.23),
- Indus Basin (2.24),
- Tethyan Belt (2.25) including the Lower Himalayas (2.251), the Higher Himalayas (2.252), the Kohistan Island Arc Complex (2.253), the Karakorum Block (2.254) and the Hindukush Elements (2.255).

The tectonic and structural features and their significance are described in Chapter 5 under the following headings:
- Shield elements (5.21),
- West Pakistan Foldbelt (5.23),
- Chagai-Ras Koh Volcanic Arc (5.24).

The tectonic and structural features of the Indus Basin and the Tethyan Belt are not dealt with separately, because the discussion of these features is included in Chapters 2.24, 2.25 and 6.7.1.

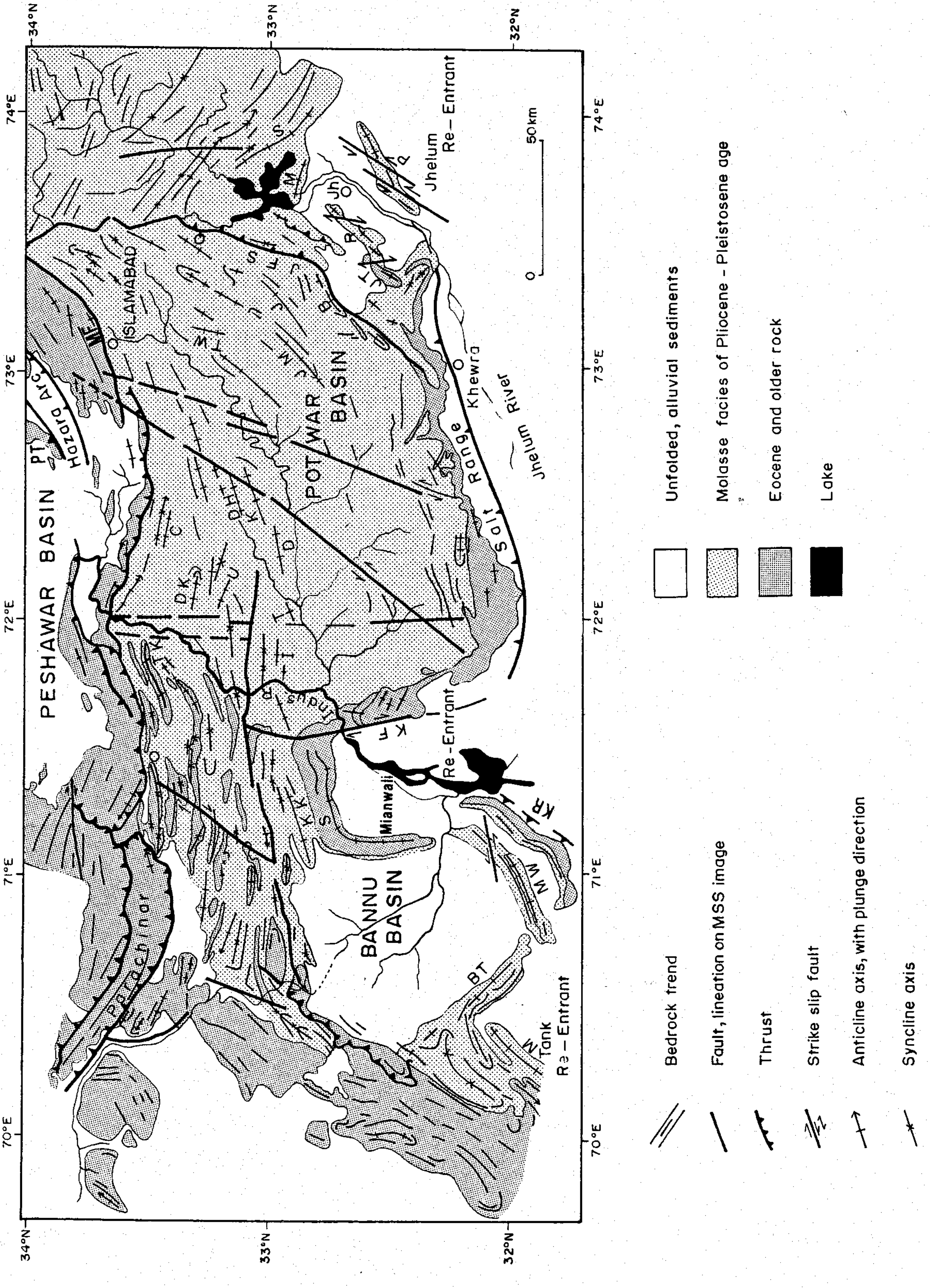


Fig. 2.6. LANDSAT MSS structural interpretation of the Kohat-Potwar area (after BANNERT 1986, map 2 and HILLER 1993, fig. 2). JFS: Jhelum Fault System; Jh: Jhelum; KF: Kalabagh Fault; MF: Murree Fault; PT: Panjal Thrust; DK, DH, O, etc.: Various Anticlines.

2.21 The Chagai and Ras Koh area

(DIETRICH BANNERT)

Between the Afghan Block in the southern part of the Eurasian Plate and the accretionary geosynclinal flysch wedge in the Makran area (Fig. 2.5), there is a volcanic arc. It consists of two parts, the Chagai Hills in the north and the Ras Koh Range to the southeast (Fig. 2.7). WITTEKINDT & WEIPPERT (1973) reported evidence of arc activity along the eastern boundary of the Afghan Block. To the south of the two ranges, an apron of folded flysch sediments appears, the Mirjawa and Ras Koh Flysch Belts, which are roughly 100 km across strike. To the south, the Ras Koh flysch is separated from the flysch ranges of the central Makran by the Mashkhel Depression (Hamun-i-Mashkel). The exposures are lobate and convex to the south similar to the flysch lobes of the central and southern Makran. To the west the volcanic arc is cut by the Harirud Fault that separates the western Afghan Block from the Lut Block near Zahedan in Iran (STÖCKLIN 1977). To the east, the sinistral Chaman Fault terminates the Ras Koh Range and forms part of the boundary between the Eurasian Plate and the Indo-Pakistan Plate (Fig. 2.7).

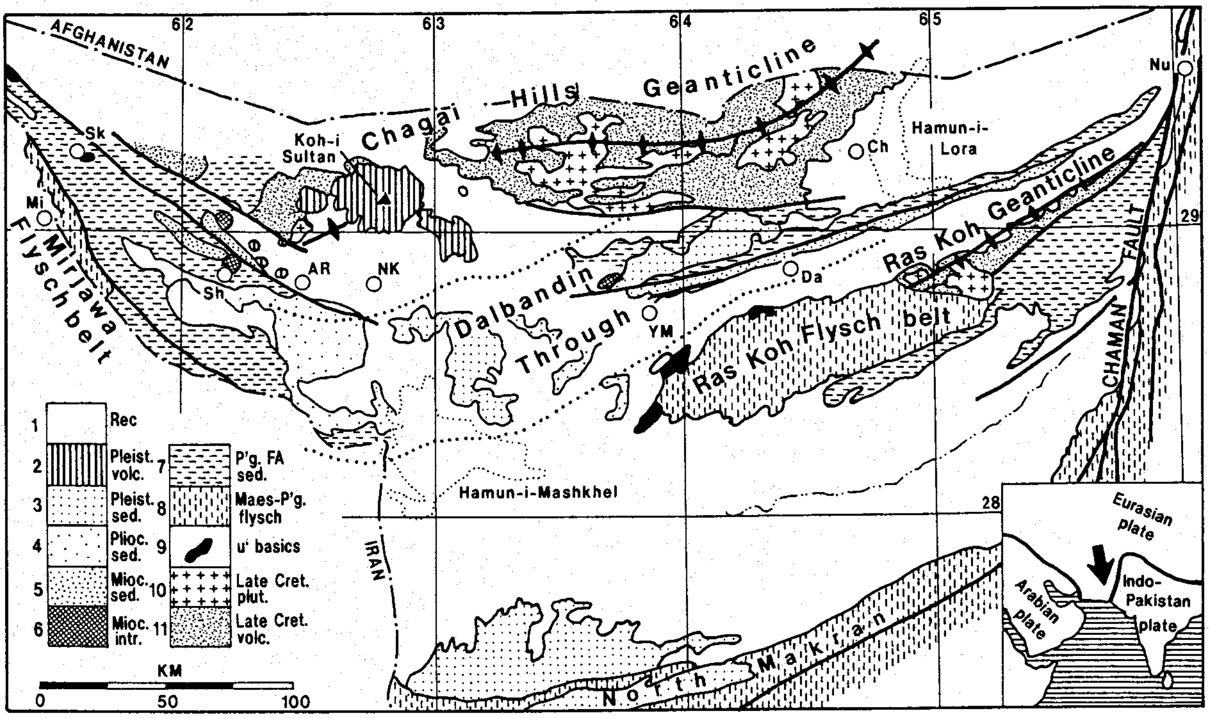


Fig. 2.7. Geological sketch-map of the Chagai and Ras Koh area (after ARTHURTON et al. 1982) Sources: JONES (1960), BAKR & JACKSON (1964). (1) Recent and undivided Quaternary sequences; (2) Pleistocene volcanics; (3) Pleistocene sediments; (4) Pliocene sediments; (5) Miocene sediments; (6) Miocene intrusives; (7) Palaeogene forearc sediments; (8) Maestrichtian-Palaeogene flysch; (9) ultrabasic igneous rocks; (10) Late Cretaceous-Palaeogene plutonic igneous rocks; (11) Late Cretaceous volcanic rocks; AR: Alam Reg; Ch: Chagai; Da: Dalbandin; Mi: Mirjawa; NK: Nok Kundi; Nu: Nushki; Sh: Shor Nalla; Sk: Saindak; YM: Yak Mach. Limits of Dalbandin Trough (heavy dots) based on aeromagnetic data. Light dots show limits of present topographical depressions.

The Chagai and Ras Koh area was mapped and investigated by the Hunting Survey Corp. (1960). Earlier, only VREDENBURG (1901) visited the area and recognized its volcanic nature. FARHOUDI & KARIG (1977) and JACOB & QUITTMEYER (1979) regarded the Chagai and Ras Koh Ranges as the volcanic arc associated with the subduction zone farther south below the Makran geosyncline, where oceanic material of the Arabian Plate has been subducted under the southern margin of the Eurasian Plate (Afghan Block). ARTHURTON et al. (1982) followed this concept when they gave a modern account of the area. They termed the Chagai Hills as **Chagai Hills Geanticline** and the Ras Koh Range as the **Ras Koh Geanticline**. Between the two, the **Dalbandin Trough** appears, filled by Palaeogene, Miocene and Pleistocene deposits. It is believed to be the result of a sinistral transcurrent fault that separated an early Chagai-Ras Koh Volcanic Arc (SILLITOE 1978).

2.211 The Chagai Hills

The Chagai Hills Geanticline is a complex of andesitic volcanics of Pre-Maestrichtian age (Sinjrani Volcanic Group; Hunting Survey Corp. 1960). Widespread intrusions of granodioritic, dioritic, and granitic rocks affected the Sinjrani and Juzzak Formations (Hunting Survey Corp. 1960) of Late Cretaceous and Paleocene age. The area of the present Chagai Hills became land. Magmatic activity was resumed during the Paleocene in the Mirjawa Flysch Trough and in front of the Chagai Hills Geanticline, lasting until the Eocene. During the Miocene, the Shor Koh Intrusions of doleritic sills and dykes occurred in the western Chagai Hills Geanticline. During the Pleistocene, the Koh-i-Sultan volcano erupted in the western Chagai Hills Geanticline, contemporary with the Bazman and Kuh-i-Taftan eruptions in Iran. The Sinjrani Volcanic Group includes tuffs, andesitic lavas and volcanic agglomerates with boulders of hippuritic limestone (VREDENBURG 1901). ARTHURTON et al. (1982) reported a thickness of 4 km to 10 km. According to aeromagnetic surveys (FARAH et al. quoted in ARTHURTON et al. 1982), the volcanic deposits are restricted to the Chagai Hills and do not underlie the Dalbandin Trough to the south. During Maestrichtian time the volcanic activity was followed by the deposition of conglomerate and shallow-water limestone, the Humai Formation (Fig. 3.8; VREDENBURG 1901). The conglomerate contains pebbles of granitic rocks from the Chagai Hills and dips southwards under the Dalbandin Trough. North of Alam Reg, the Humai Formation overlies several hundred meters of turbidites, including limestone conglomerates, indicating early erosion in the Chagai Hills Geanticline (ARTHURTON et al. 1982).

2.212 The Dalbandin Trough

The Dalbandin Trough is a rather straight northeast-striking valley south of the Chagai Hills that ends in the Hamun-i-Mashkhel. Hunting Survey Corp. (1960) connected it with the Mirjawa Trough and the Saindak-Alam Reg Basin. Overlying the Humai Formation in the Dalbandin Trough is a Tertiary sequence, described by ARTHURTON et al. (1982), beginning with the Rakshani Formation (Fig. 3.9) of Paleocene age. In its lower part, this sequence consists of mudstone, volcanoclastic sandstone, and thin-bedded limestone comparable to the Juzzak Formation (Hunting Survey Corp. 1960) in the Chagai Hills Geanticline. The upper part consists of shallow water limestone, the Chapper (reef-bearing) Limestone and the Gat-i-Hamun Limestone (ARTHURTON et al. 1982), alternating with cross-bedded sandstone.

During Oligocene times, the Chagai Hills Geanticline and the Mirjawa and Ras Koh Flysch Belt were exposed to subaerial erosion and continental deposition. The Amalaf Formation (Figs. 3.8, 3.9; see Chapter 3.41) was deposited in this period of time in a fluviatile estuarine environment. During the Miocene, the Dalbandin Red Formation (ARTHURTON et al. 1982; see Chapter 3.41) was deposited unconformably over the Amalaf Formation as the Mirjawa Flysch Belt and above the Nauroz Formation in the Ras Koh Flysch Formation (ARTHURTON et al. 1982). The Dalbandin Red Formation consists of continental sediments accumulated in the Dalbandin Trough and the Saindak-Alam Reg Basin. The Dalbandin Red Formation is partly gypsiferous and probably of lacustrine origin. In the vicinity of the Laki Koh Fault that runs ENE north of Dalbandin, the basal conglomerate includes abundant coarse material of local origin, such as blocks of Paleocene limestone north of Yak Mach (Yak Mach Conglomerate Formation). According to ARTHURTON et al. (1982), this indicates a contemporaneous activity along the fault. The Dalbandin Red Formation is at least 3,000 m thick. It is regarded by the same authors to be equivalent to the Miocene-Pliocene Upper Red Formation of Iran (STÖCKLIN et al. 1972).

During the Pliocene, two tectonic phases influenced the Dalbandin Trough. One produced folds with axes that change from northeast near Yak Mach to east near Dalbandin. The other phase involved major reverse faulting and folding along arcuate thrusts convex to the south. The alignment of the faults (e.g. Chappar Fault, Laki Koh Fault) reflects the general alignment of the Dalbandin Trough itself. During the Pleistocene, the Kamerod Formation (Hunting Survey Corp. 1960) was deposited. It consists of reddish and white lacustrine silt, clay, sandstone and conglomerate. The dips are generally shallow.

2.213 The Ras Koh Geanticline and Ras Koh-Mirjawa Flysch Belts

The Ras Koh area includes the Ras Koh Ranges or Ras Koh Geanticline and the Ras Koh Flysch Belt (ARTHURTON et al. 1982). As indicated previously, the Ras Koh Flysch Belt can be correlated with the Mirjawa Flysch Belt to the west.

The Ras Koh Geanticline has stratigraphic units that are lithologically similar to those in the Chagai Hills Geanticline. During the Late Cretaceous, at least 6 km of volcanoclastics accumulated (Kuchakki Volcanic Group; Hunting Survey Corp. 1960), but the andesitic lava flows are not as widely distributed as in the Chagai Hills Geanticline. Limestone strata comparable to those in the Humai Formation are present at the top of the Kuchakki Volcanic Group.

The Ras Koh Flysch Belt contains strata as old as Maestrichtian (?). In the eastern part, sedimentation in a marine environment commenced during the Paleocene, when the Rakhshani Formation was deposited. There are bedding-parallel lenses of ultramafic rocks as much as 15 m wide and 1.5 km long, including pyroxenite and peridotite, commonly containing chromite (AHMED 1956, Hunting Survey Corp. 1960, ARTHURTON et al. 1982). Although Hunting Survey Corp. (1960) regarded the ultramafics as intrusions (Bunap Intrusions), the modern interpretation by FARHOUDI & KARIG (1977), JACOB & QUITTMEYER (1977) and ARTHURTON et al. (1982) is that they are masses of an obducted ocean floor. At the end of the Paleocene, the flysch was folded and thrust. During the Early Eocene, the shallow-water Kharan Limestone Member (Fig. 3.9) was deposited in the Ras Koh Flysch Belt. It has been only moderately folded.

After the deposition of the Kharan Limestone Member, the sedimentation changed again to the more clastic Eocene-Oligocene Nauroz Formation (Hunting Survey Corp. 1960). During the Miocene, terrigenous sedimentation prevailed, with several conglomeratic layers above unconformities (Dalbandin Red Formation).

In the area of the Mirjawa Flysch Belt, the Paleocene Juzzak Formation overlies the Upper Cretaceous Sinjrani Volcanics. The Juzzak Formation sequences are regarded as fore-arc sediments by ARTHURTON et al. (1982). Andesitic lava beds are present within the sequence, and tuff marks the top of the sequence near Alam Reg. In this area, the Juzzak Formation overlies the Saindak Formation (Fig. 3.9; Hunting Survey Corp. 1960; see Chapter 3.41). They are generally of Eocene age but some fossils apparently belong in the Paleocene. According to Hunting Survey Corp. (1960), the youngest beds may contain Oligocene fossils. A change in sedimentation occurred during the Oligocene, when the Amalaf Formation was deposited.

The Late Cretaceous-Palaeogene stratigraphic units (see Chapters 3.33, 3.41) in the western part of the Mirjawa area differ from those farther east. The Mirjawa Flysch Formation (ARTHURTON et al. 1982) was deposited generally south and west of the Juzzak Formation. Its age is Maestrichtian through Paleocene; ARTHURTON et al. (1982) compared it with the Ras Koh Flysch farther east. The flysch sediments are composed of mudstone, shale, and turbiditic, volcanoclastic sandstone. Towards the end of the Paleocene, the Mirjawa Flysch Trough was elevated and folded. During the Eocene, the limestone of the Paleocene-Eocene Washap Formation (Hunting Survey Corp. 1960) was most likely deposited on a shoal representing the structural high of the folded Mirjawa Flysch Formation (ARTHURTON et al. 1982). The Amalaf Formation (Fig. 3.9) was presumably deposited during the Oligocene (Hunting Survey Corp. 1960). The Formation can be subdivided into two parts totalling 1,800 m. The upper part contains volcanics, including ash and agglomerates in beds as much as 10 m thick. Andesitic lava flows are present, similar to those in the Sinjrani and Juzzak Formations.

It can be concluded, that the earliest folding in the Mirjawa-Ras Koh Flysch Belt occurred during the Early Paleocene, when the Rakhshani Formation and the Ras Koh Flysch were intensively folded and followed by shallow-water sediments. This folding coincided with the obduction of ophiolites in the Bela-Waziristan Ophiolite Zone (ALLEMANN 1979; Fig. 2.2), signalizing the collision of the Arabian Plate with the Indo-Pakistan Plate and simultaneously with the southern margin of the Eurasian Plate. The Ras Koh Flysch Belt was thrust northward against the Ras Koh Geanticline and both structures formed a single landmass, where the early Eocene shallow-water Kharan Limestone Member (Fig. 3.9) was deposited at the southern shore.

Marine sedimentation terminated during the Late Eocene, and the entire Chagai, Mirjawa and Ras Koh area finally emerged. The accumulation of continental red series has prevailed up to the present; the partly gypsiferous and saline sedimentation was periodically interrupted by orogenetic movements.

2.214 The Mashkhel Depression

The Mashkhel Depression is a flat area, including the Hamun-i-Mashkhel playa lake and the Kharan Desert; it is covered by Quaternary sand. An aeromagnetic survey (FARAH et al., quoted in ARTHURTON et al. 1982), confirmed the presence of a large thickness of sediments beneath the Quaternary cover. The depression is 100 km wide from north to south. In the north it is bordered by the Mirjawa and Ras Koh Ranges and, in the south, by the central Makran flysch ranges. It can be assumed that the sedimentary fill beneath the Quaternary cover of the Mashkhel Depression consists of flysch ranging in age from Late Cretaceous through Miocene. The Mashkhel Depression is thought to be the fore-arc basin (FARHOUDI & KARIG 1977) of the modern subduction zone below the Makran Flysch.

2.22 The Makran-Khojak-Pishin Flysch Zone

(HILAL A. RAZA and DIETRICH BANNERT)

The Makran-Khojak-Pishin Flysch Zone of Pakistan (Fig. 2.5) is a part of the continental margin of the Afghan Block in the southern part of the Eurasian Plate. It is a continuous zone of sediments, mostly of geosynclinal flysch nature, locally grading into orogenic molasse sediments. It can be divided into three segments characterised by different tectonic styles: the **Makran-**, **Khojak-**, and **Pishin** (= Katawaz in Afghanistan, TAPPONIER et al. 1981) segments.

2.221 The Makran Flysch Segment

The Makran region displays the best exposed arc-trench gap in the world, forming the seaward edge of a large accretionary sediment prism (Fig. 2.8). The accretionary wedge is exceptionally broad, extending more than 300 km northward from the prism front which lies 100 km south of the present shoreline in the Gulf of Oman (WHITE 1979, PLATT & LEGGETT 1986).

The Makran Flysch Segment is separated in the west by the Oman Line (FARHOUDI & KARIG 1977) from the oil producing Zagros region in Iran. From the Oman Line,

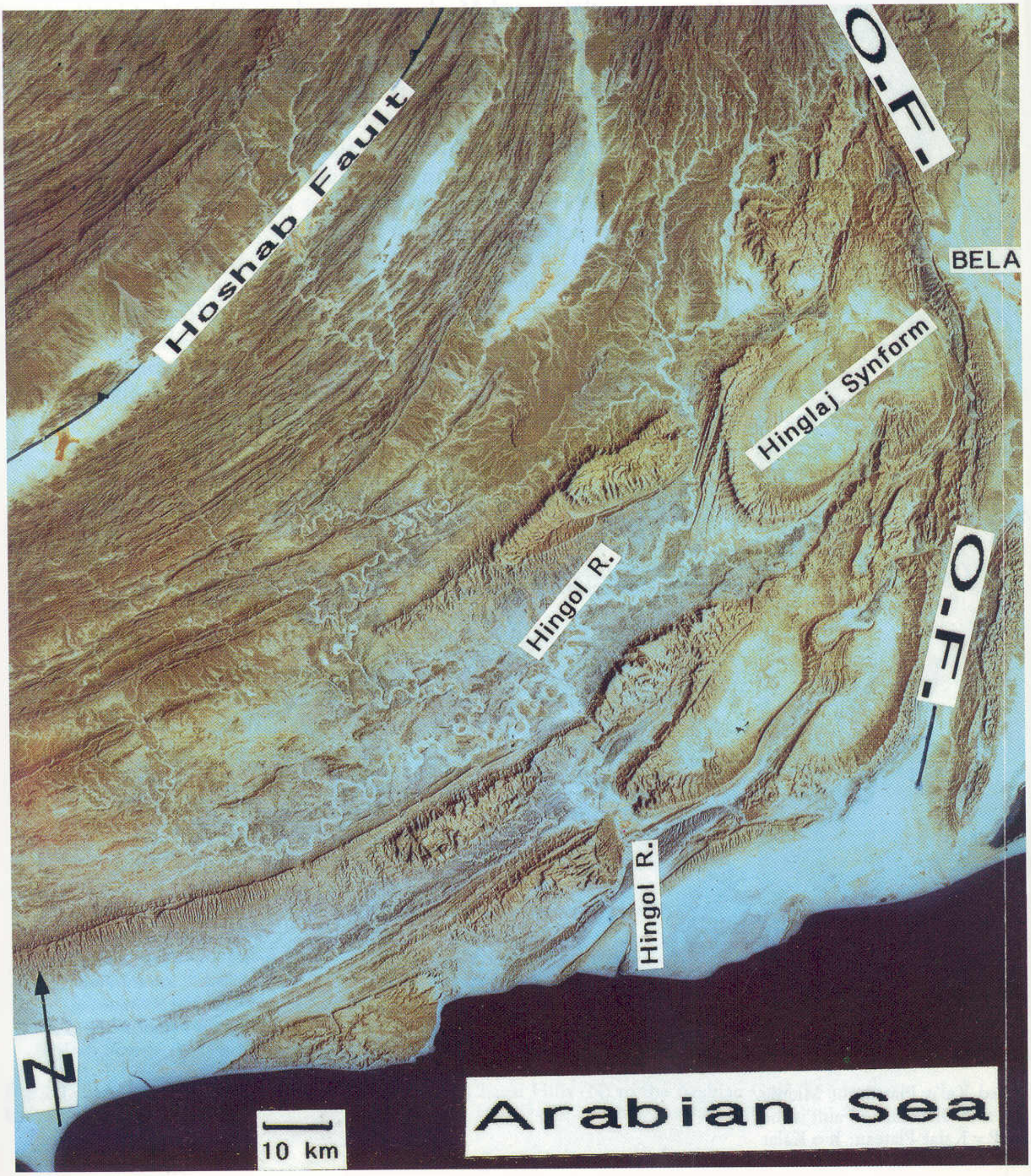


Fig. 2.9-A. LANDSAT image of the Hinglaj Synform north of the Makran coast. The lighter coloured massive Pliocene Talar Sandstone is interpreted as a delta deposit. OF = Ornach-Nal Fault (after BANNERT et al. 1992, fig. 4).

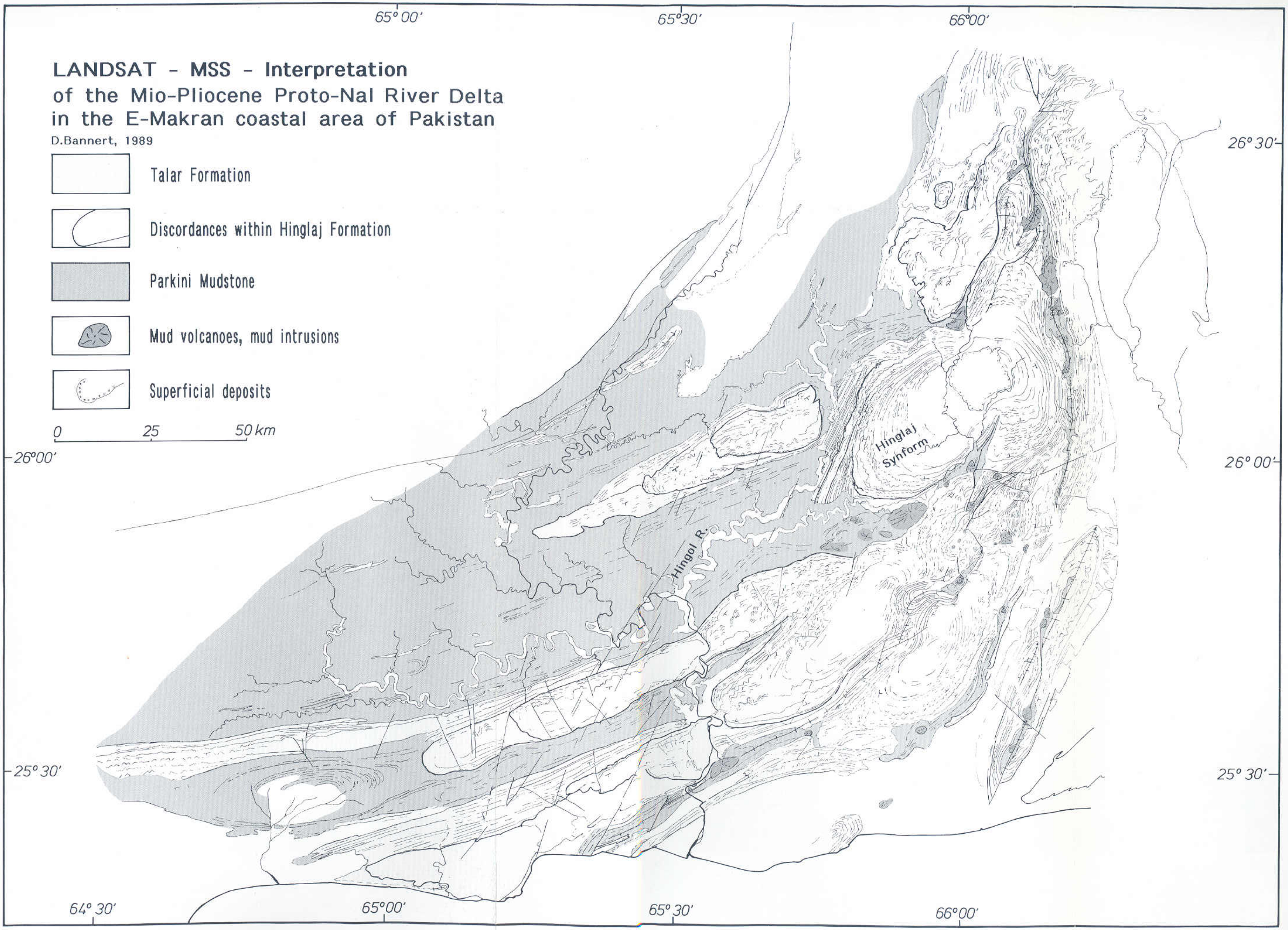

LANDSAT - MSS - Interpretation
of the Mio-Pliocene Proto-Nal River Delta
in the E-Makran coastal area of Pakistan
D.Bannert, 1989
Talar Formation
Discordances within Hinglaj Formation
Parkini Mudstone
Mud volcanoes, mud intrusions
Superficial deposits
0
25
50 km
65° 00'
65°30'
66°00'
64° 30'
65°00'
65° 30'
66°00'
26° 30'
26°00'
26° 00'
25° 30'
25° 30'
Hinglaj Synform
Hingol R.

Fig. 2.9-B. Geological interpretation of the LANDSAT image shown in Fig. 2.9-A (after BANNERT et al. 1992, fig. 3).

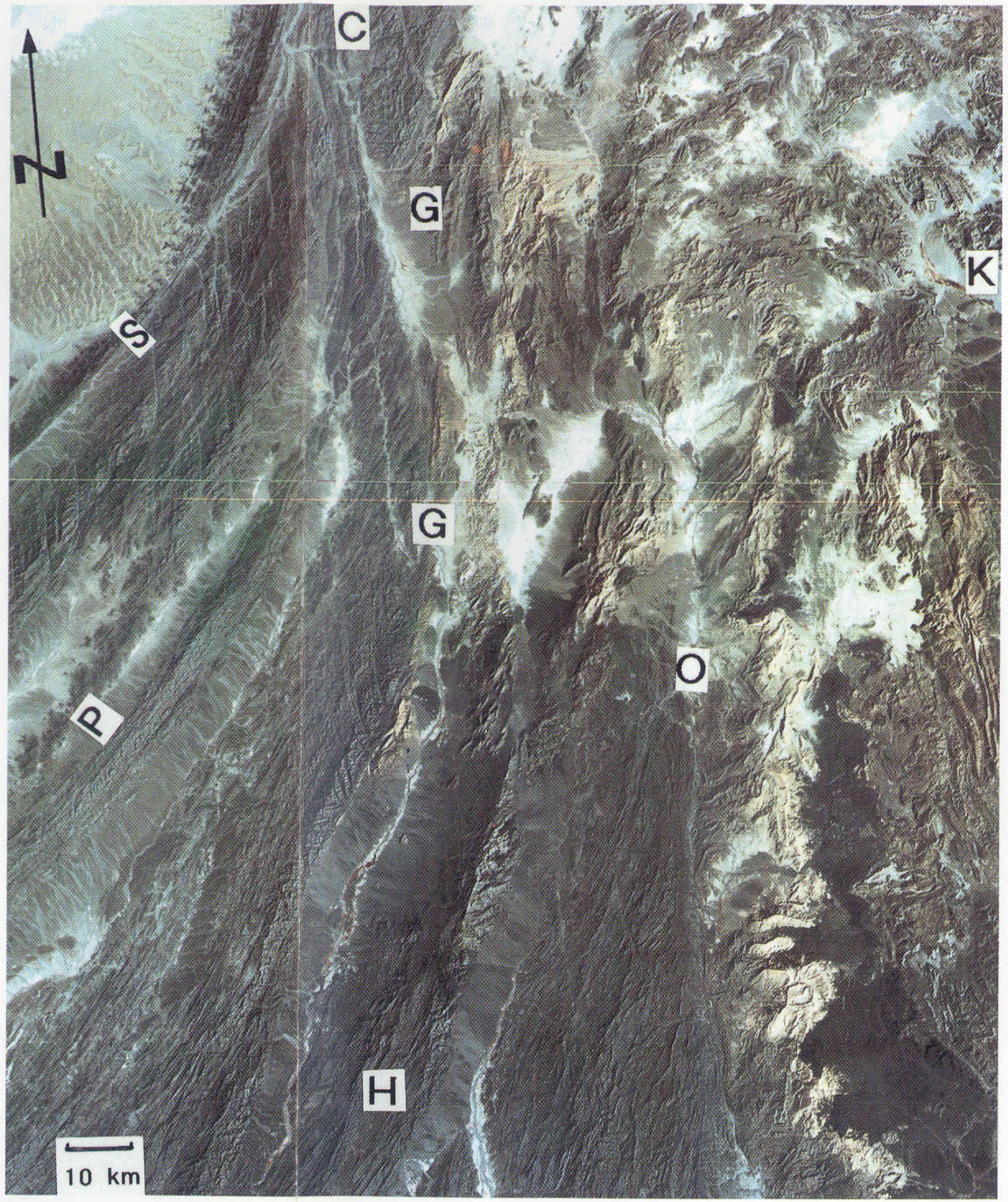


Fig. 2.10. LANDSAT image of the northeastern Makran Flysch Segment west of Khuzdar. The left part of the image displays the Makran Flysch, in the lower right corner are dark rocks of the Bela-Waziristan Ophiolite Zone, and the right part is covered by Mesozoic shelf rocks of the Khuzdar Block. C = Chaman Fault; G = Ghazaband Fault; H = Hoshab Fault; K = Khuzdar; O = Ornach-Nal Fault; P = Panjgur Fault; S = Siahan Fault.

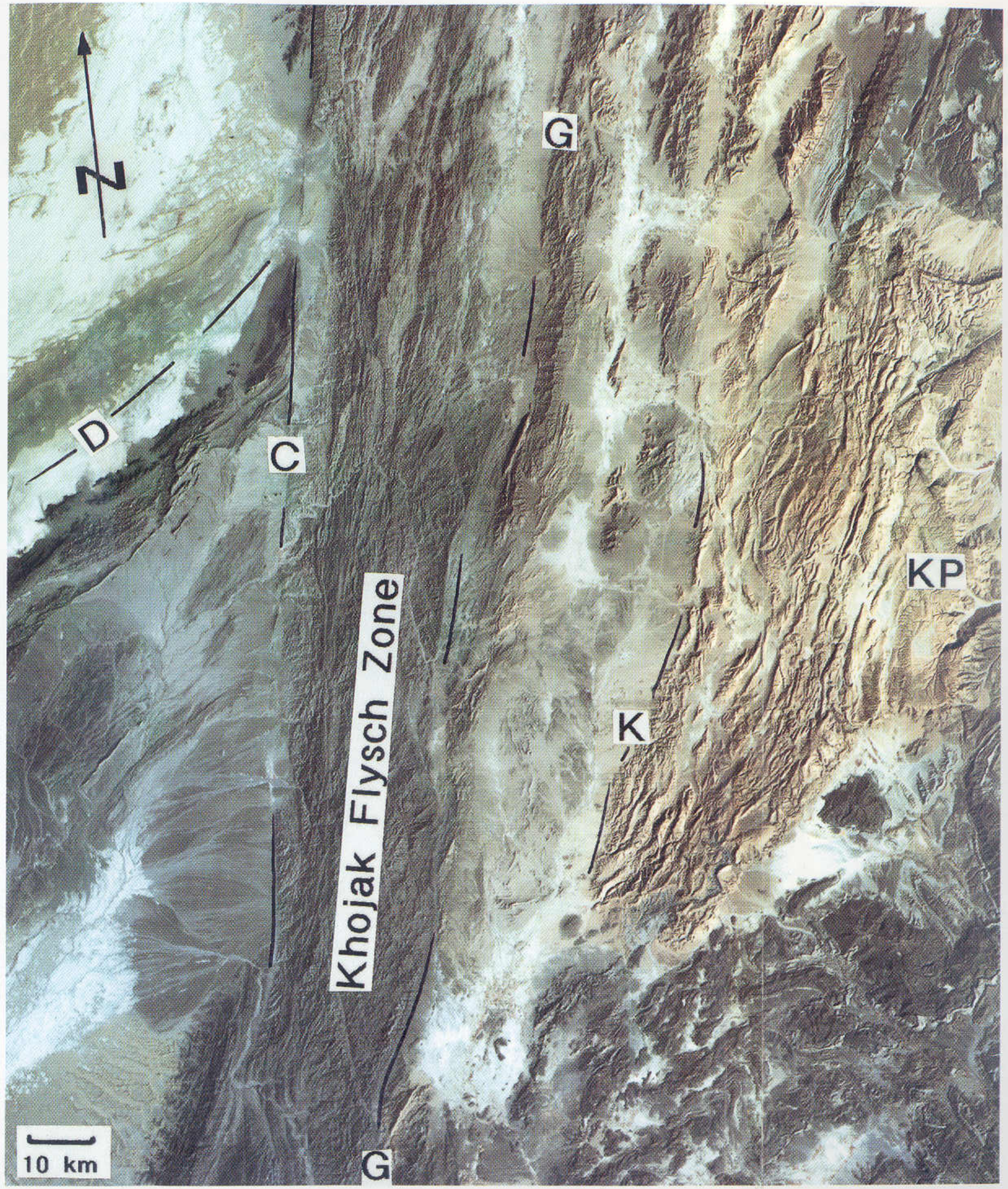


Fig. 2.11. LANDSAT image of the area northwest of Khuzdar displaying the light coloured Kalat Plateau of Middle Eocene Spintangi Formation and the north-trending strike-slip faults. Between Chaman Fault and Ghazaband Fault is the Khojak Flysch Segment. C = Chaman Fault; D = Dalbandin Fault; G = Ghazaband Fault; KP = Kalat Plateau; K = Kalat Fault.

this part of the flysch zone stretches eastward to the extensions of the north-trending Chaman, Ghazaband, and Ornach-Nal Faults (Fig. 2.10, fold-out). The southern limit of the Makran Flysch Segment is marked by an active subduction trench in the Gulf of Oman (JACOB & QUITTMEYER 1979). In the north, the Makran Flysch Segment is bordered by the Chagai-Ras Koh Arc and the associated Mashkhel Depression which is considered to be a fore-arc basin above the Makran subduction complex (FARHOUDI & KARIG 1977, RAZA & ALAM 1983).

The age of the flysch sediments ranges from Late Cretaceous in the north to Recent in the Gulf of Oman. Exposures of Mesozoic and Palaeogene sediments, including sporadic outcrops of Eocene reefoid limestone, are found at Ispikan near the Iranian border. These rocks are highly disturbed and their stratigraphic relationship with the underlying and overlying rock units is yet to be established. However, in southeast Iran to the east of the Lut Block, sediments of Late Cretaceous, Early to Middle Eocene, Oligocene and Miocene ages are found in the Kuh-i-Berg area (MCCALL & KIDD 1982). ARTHURTON et al. (1982) described the first occurrence of turbiditic sediments above the Sinjrani Volcanic Group west of the Chagai Hills Geanticline which are at least in part of Maestrichtian age. They belong to the Mirjawa Flysch Belt and might form a westward extension in the flysch sediments of the Ras Koh Flysch Belt. During the Paleocene, the flysch sedimentation continued in the area between the Saindak-Alam Reg Basin and the Dalbandin Trough to the west and south of the Chagai Hills Geanticline (Juzzak

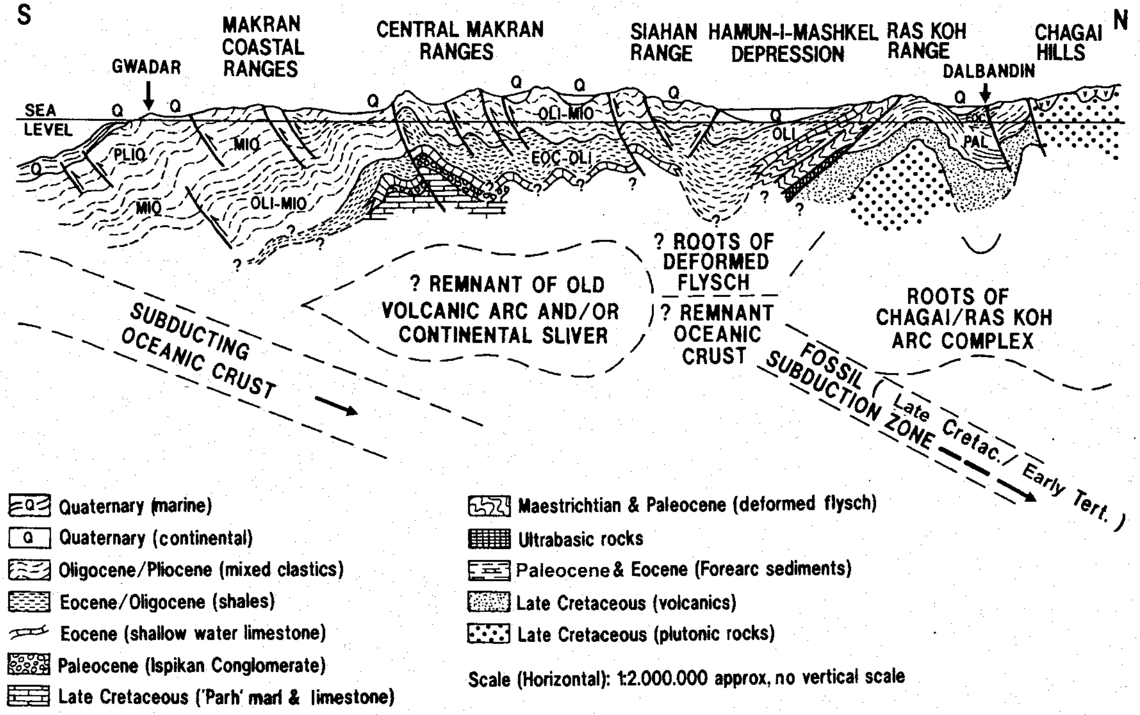

S
N
GWADAR
MAKRAN COASTAL RANGES
CENTRAL MAKRAN RANGES
SIAHAN RANGE
HAMUN-I-MASHKEL DEPRESSION
RAS KOH RANGE
CHAGAI HILLS
DALBANDIN
SEA LEVEL
Q
PLIO
MIO
OLI-MIO
EOC-OLI
OLI
EOC
PAL
?
? ROOTS OF DEFORMED FLYSCH
? REMNANT OF OLD VOLCANIC ARC AND/OR CONTINENTAL SLIVER
? REMNANT OCEANIC CRUST
ROOTS OF CHAGAI/RAS KOH ARC COMPLEX
SUBDUCTING OCEANIC CRUST
FOSSIL SUBDUCTION ZONE (Late Cretac./ Early Tert.)
Quaternary (marine)
Quaternary (continental)
Oligocene/Pliocene (mixed clastics)
Eocene/Oligocene (shales)
Eocene (shallow water limestone)
Paleocene (Ispikan Conglomerate)
Late Cretaceous ('Parh' marl & limestone)
Maestrichtian & Paleocene (deformed flysch)
Ultrabasic rocks
Paleocene & Eocene (Forearc sediments)
Late Cretaceous (volcanics)
Late Cretaceous (plutonic rocks)
Scale (Horizontal): 1:2.000.000 approx, no vertical scale

Fig. 2.8. Schematic structural cross-section from the Chagai Hills (N) to the Arabian Gulf (S) (after DOLAN et al. 1987, fig. 3.4).

Formation, Hunting Survey Corp. 1960). The occurrence of reefal limestone in the Ras Koh Flysch Belt above the turbidites signalizes shallow water conditions. In the Ras Koh Flysch Belt, sheared ophiolitic rocks occur which Hunting Survey Corp. (1960) named Bunap Intrusions. ARTHURTON et al. (1982) considered them to be remnants of a former subduction complex tectonically emplaced in the flysch deposits.

The northern and central Makran Ranges are dominated by abyssal accretionary sediments of Oligocene-Miocene age, whereas prograding upper slope and shelf sediments mostly cover the coastal region. Miocene through Pleistocene sediments are widespread in the coastal Makran area (Fig. 2.8).

The shales of the Hoshab and Siahan Formations (Fig. 3.9) of Oligocene age (Hunting Survey Corp. 1960) mark the beginning of trench sedimentation in the region. They are succeeded by turbiditic sandstones of the Panjgur Formation (Fig. 3.9), representing basin plain sediments deposited at the consuming plate boundary. These sediments were compressed to form steep folds and imbricate wedges with accretion of more sediments. Abyssal plain turbidites prograde into upper slope and shelf sediments which cover the coastal Makran region. These sediments exhibit rapid shelf to slope to basin plain transitions. The lithologies corresponding to these three broad zones are strongly diachronous with complex lateral facies relationships. In the Makran, the sedimentary sequence of Oligocene to Pleistocene age is subdivided into five stratigraphic units:

- Marine shoreline deposits of Early to Late Pleistocene age (Ormara and Jiwani Formations, Fig. 3.9; Hunting Survey Corp. 1960), present in coastal Makran;
- Neritic, massive and monotonous sequences of calcareous mudstones of Pliocene age (Chatti Member, Fig. 3.9; Hunting Survey Corp. 1960), present in coastal Makran;
- Shelf sediments of Late Miocene-Pliocene age east and west of the Pasni Anticlinorium (Talar Sandstone, Fig. 3.9; Hunting Survey Corp. 1960);
- Sediments of Miocene age of an accretionary fore-arc basin rapidly prograding from deep water (Parkini Formation, Fig. 3.9; Hunting Survey Corp. 1960) to shallow marine (Talar Sandstone) depositional environment (CRAME 1989) of the Hinglaj Formation (Fig. 3.9);
- Rocks of Oligocene-Early Miocene age deposited in an oceanic basin and consisting of abyssal muds (Hoshab and Siahan Formations; Fig. 3.9), and turbidites (Panjgur Formation, Hunting Survey Corp. 1960).

Most of the sediments are turbiditic sandstone, siltstone and shale. The Miocene and younger sediments in the coastal area are not as much affected by tectonic deformation as the older rocks of the central and northern Makran. In the central part of the coastal area, the Pasni Anticlinorium may be considered as the remnant sedimentary cover of the subducting plate, whereas to the west and east mildly folded younger prograding shelf sediments of shallow water origin occur. In the east, towards the Ornach-Nal Fault, the Parkini Formation (Fig. 3.9) of deep water origin grades abruptly into the deltaic Talar Sandstone of the Hinglaj Formation (Fig. 3.9). LANDSAT image interpretation (BANNERT et al. 1992) indicates large sedimentary slumps of the deltaic sediments, forming the Hinglaj Synform and other conspicuous features in the area (Figs. 2.9 A, 2.9 B, fold-out).

The accretionary wedge in the Makran segment grew continuously during the Late Tertiary and Quaternary. The tectonic process generated a pile of nappes and schuppen which generally advanced southwards (Hunting Survey Corp. 1960, LEGGETT & PLATT 1984). East of 65° E, the flysch nappes gradually turn towards the north. There, numerous north-trending faults which belong to the southward extension of the Chaman and Ghazaband Faults dissect the northeast to north striking flysch sediments (Figs. 2.10, 2.11, fold-out).

2.222 The Khojak Flysch Segment

East of 65° E and north of 28° N, the structures of the Makran Flysch Segment gradually change from east-trending into the north-trending of the Khojak Flysch Segment, which extends between the Chaman Fault in the west and the Ghazaband Fault (Fig. 2.10) in the east. The Khojak Flysch Segment can be followed for 300 km to the north (Fig. 2.5). There, it gradually loses its tight and imbricate structure giving way to the fold and nappe structures of the Pishin Flysch Segment (= Katawaz Basin; TAPPONIER et al. 1981). The width of the Khojak Flysch Segment across the strike is only 30 km.

The sediments in the Khojak Flysch Segment are of Oligocene to Miocene age. However, detailed stratigraphic studies have not yet been made and might in future yield ages for the flysch similar to those in the Makran area. The flysch sediments dip very steeply. They are dissected parallel to bedding planes by numerous longitudinal, mostly sinistral, strike-slip faults (Fig. 2.11, fold-out). Together with the Chaman Fault to the west and the Ghazaband Fault to the east, these strike-slip faults facilitated the indention of the Indo-Pakistan Plate into the Afghan Block of the Eurasian Plate.

2.223 The Pishin Flysch Segment

Approximately 30 km north of Quetta, the Khojak Flysch Segment bends to the northeast and its internal structure changes progressively from tight and imbricate sediment wedges into intact folds. The width of 30 km across strike also changes into a 100 km wide belt of fold lobes, bent convex to the southeast, similar to the flysch lobes in the Makran. The Pishin Flysch Segment (Fig. 2.5) is located for the most part in Afghanistan territory. It is wedged between the Kabul Block of the Eurasian Plate in the north and the Bela-Waziristan Ophiolite Zone in the south; it finally terminates at the Sarobi Fault, thrust between the ophiolites south of the Kabul Block and Khost near 70° N and 34° E (BAKR & JACKSON 1964, WITTEKINDT & WEIPPERT 1973, TAPPONIER et al. 1981). SOKOLOV & SHAH (1966) and RAZA et al. (1989) considered the Pishin Flysch Segment to be a rear depression developed in the west and north of the Sulaiman mega-anticlinorium. This was formed after the collision of the Indo-Pakistan Plate and the Afghan Block of the Eurasian Plate, when the Pishin Flysch Trough developed into a molasse basin during the Oligocene (WITTEKIND & WEIPPERT 1973, TAPPONIER et al. 1981).

The Pishin Flysch Segment contains sediments ranging in age from Paleocene through Pliocene. In Pakistan north of the Zhob Valley, the oldest exposed rocks belong to the Nisai Formation (Fig. 3.9; Hunting Survey Corp. 1960). This Formation contains a high proportion of reefoid limestone with local development of shale, sandstone and conglomerate. Eocene flysch sandstone overlies the serpentinite of the Bela-Waziristan Ophiolite Zone (ALLEMANN 1979). The Nisai Formation is transitionally succeeded by the marine Murgha Faqirzai Formation (Fig. 3.9; Hunting Survey Corp. 1960) of Oligocene age which is of flysch nature. The Murgha Faqirzai Formation is overlain by the Shaigalu Sandstone (Fig. 3.6, Shaigalu Member) of Late Oligocene through (?) Pliocene age (Hunting Survey Corp. 1960). It is composed of interbedded sandstone and shale mainly deposited in a marine environment. In its upper part there is evidence of nearshore deposition. North of the Zhob Valley, conglomerate and ferrugineous beds are exposed which are considered to have been derived from nearby sources. The Shaigalu Member (Fig. 3.9) is overlain by the Bostan Formation (Fig. 3.9; Hunting Survey Corp. 1960) which consists of a poorly consolidated assemblage of clay, silt, conglomerate, and thin-bedded sandstone. Its distribution is restricted to the present main valleys.

The Afghanistan part of the Pishin Flysch Segment is called the Katawaz Basin. In the region between Khost and Gardez, TAPPONIER et al. (1981) observed that the sediments above rocks of the Khost Ophiolite Complex grade from continental and epicontinental to deep pelagic flysch, ranging in age from Paleocene to Eocene. The flysch grades upwards into an Oligocene-Miocene sequence of shallow water sandstone and shale.

The thickness of the flysch sediments of the Pishin Flysch Segment might range between 7,000 m and 8,000 m (TAPPONIER et al. 1981). WITTEKINDT & WEIPPERT (1973, section C-D) show the magnetic basement of the Pishin Flysch Segment to be as deep as 4,000 m below sea level.

The Pishin Flysch Segment consists of a number of nappes in which broad synclines occur with their axes commonly plunging at both ends. The limbs of the synclines are generally steeply dipping or vertical. Anticlines are much smaller in size, or absent and replaced by faults (SOKOLOV & SHAH 1966). Wherever preserved, the anticlines are much narrower than the synclines, having high amplitudes and steeply dipping limbs. Most of the faults are parallel to the strike of the bedding and are low angle thrusts, assumed to be nappe thrusts similar in appearance to those in the Makran Flysch Segment (BANNERT et al. 1992). Approaching the Chaman Fault, the deformation becomes more severe. The basement of the Pishin flysch in the Afghan- and Kabul Blocks is represented by the Paleozoic-Mesozoic cover of the metamorphic rocks of Gondwana. The southern limit of the Pishin Flysch Segment is the Zhob Valley Thrust, occupying the area of the Zhob Valley. There, the flysch nappes from the north are thrust on obducted serpentinite and associated rocks of the Bela-Waziristan Ophiolite Zone, overlain by Early Tertiary flysch-type rocks (ALLEMANN 1979).

2.23 The West Pakistan Foldbelt

(DIETRICH BANNERT)

The West Pakistan Foldbelt occupies the area east of the Makran-Khojak-Pishin Flysch Zone in eastern Baluchistan, western Sindh and part of Waziristan, and west of the Indus Plain (Fig. 2.5; Figs. 5.7, 5.8, 5.9, geol. map). The West Pakistan Foldbelt is located on the Indo-Pakistan Plate and was folded during the collision process, when the Indo-Pakistan Plate underwent basement segmentation (BANNERT et al. 1992). It is a mountainous region with altitudes exceeding 3,000 m (Mt. Zarghun 3,562 m) east of Quetta.

The rocks overlying the basement of the Indo-Pakistan Plate are mainly of Mesozoic and Tertiary age. The Mesozoic sediments are of marine geosynclinal and partially pelagic origin. During the end of the Cretaceous, the Pab Sandstone (Fig. 3.6; VREDENBURG 1901; see Chapter 3.33), a deltaic terrigenous sandstone sequence derived from the Indian Shield, was deposited in the geosynclinal pelagic environment, ending the prevailing calcareous sedimentation. The Pab Sandstone attains its greatest thickness of 1.700 m in the Sulaiman Range and in the Pab Range of the Khuzdar Block (Hunting Survey Corp. 1960, WHITE 1981). The overlying Tertiary rocks were mostly deposited under shallow-water conditions.

The boundary of the continental Indo-Pakistan Plate against the flysch sediments in the west is a zone of oceanic sea-floor rocks and their sediments, containing ultramafic masses. From south to north, these are the Bela, Muslimbagh, Zhob and Waziristan ophiolitic complexes. BANNERT et al. (1992) named this zone the Bela-Waziristan Ophiolite Zone; it is the oceanic part of the Indo-Pakistan Plate. Previous authors (VREDENBURG 1901, Hunting Survey Corp. 1960) called it the Axial Belt. Morphologically, it can be partly included in the West Pakistan Foldbelt.

From the Bela-Waziristan Ophiolite Zone, GANSSER (1979) mentioned Parh-type calcareous sediments containing pillow diabase east of Kanar. The Parh Limestone (Fig. 3.6; Hunting Survey Corp. 1960) is apparently overlain locally by the Paleocene Gidar Dhor Formation (Hunting Survey Corp. 1960), which could also be a mélange. However, it is not yet clear whether the contact is structural or sedimentary. The Parh Limestone north of Surab overlies a typical melange mudstone of greenish-blue and dark magenta with red radiolarian chert, green chert and dykes of diabase and dolerite, partly with contact metamorphism (silification) in the adjacent limestone. Similar observations can be made at Sangha Siah (= "black stone") Levy Post 19 km southeast of Surab along the road to Khuzdar, where a rhyolitic intrusion is present within the Paleocene Gidar Dhor Formation. Nearby blocks of *Globotruncana* bearing Parh Limestone, diabase, and the Jurassic Zidi Formation (Hunting Survey Corp. 1960), now Ferozabad Group, are present, either at a fault or as exotic blocks within the Gidar Dhor Formation. Greenish-blue and magenta mudstones occur nearby, indicating the possibility of a Late Cretaceous ophiolitic melange below the Gidar Dhor Formation.

About 40 km north of Khuzdar, the road cuts through folds of the Parh Limestone and the Zidi Formation (Ferozabad Group) southeast of the Diwani Fault. North of the road, 4 km north of Zawa, there is a large mass of ophiolitic melange in the core of an anticline of light-coloured limestone of Late Cretaceous age. The mélange consists of magenta marl and dark-green and dark magenta, unbedded tuffaceous material containing blocks of limestone breccia, red radiolarian chert, diabase agglomerate, red mudstone, allodaphic limestone, brown-weathered rocks and greenish-brown limestone, probably of the Goru Formation (Fig. 3.6; WILLIAMS 1959). The mélange thickness exposed is about 100 m thick. It can be concluded that Cretaceous sea-floor material containing melange sediments is covered by Cretaceous and Upper Cretaceous pelagic limestone. From the Bibai Nappe, KAZMI (1979) described agglomeratic volcanic breccia and tuff layers. They are of Late Cretaceous age because slabs of *Glolotruncana*-bearing limestone are interbedded within the tuffite layers. The alkali-basaltic components of the agglomerates indicate interplate ophiolitic volcanism. The volcanites are overlain by the Dungan Formation of Paleocene age (Fig. 3.8), a shallow marine limestone unit. Hunting Survey Corp. (1960) observed volcanic rocks from the Gogai Nappe above the Bibai Nappe east of Quetta. SPECTOR (1981) described basaltic and andesitic lavas of Cretaceous age southwest of Kalat (middle part of the Cretaceous Parh Limestone; Fig. 3.6) together with boulders of diorite, gabbro, serpentinite and basalt in conglomeratic layers.

Apart from the Cretaceous rocks, Jurassic and Triassic rocks are also present within the Bela-Waziristan Ophiolite Zone. According to Prof. A. FATMI (Geological Survey of Pakistan, Quetta; pers. comm.), the zone is characterized by the presence of rocks of Sinemurian age.

No Tertiary rocks have been found above the Cretaceous sediments in the Bela-Waziristan Ophiolite Zone.

The Indo-Pakistan Plate collided obliquely with the southern part of the Eurasian Plate during the Paleocene (SAWAR & DEJONG 1984). It was dissected into three basement blocks (BANNERT et al. 1992). The collision resulted in uplifting, folding and thrusting of the overlying sediments. The style of deformation in the sedimentary cover above the three blocks is different for each block (Fig. 2.6).

The molasse sediments that derived from the uprising Mesozoic and Tertiary rocks were deposited in the valleys of the West Pakistan Foldbelt, in the flanking lowlands of the Indus Basin and the Urak-Sibi Trough, as well as in the Zhob Valley and the frontal units of the Pishin flysch nappes.

To the east, the West Pakistan Foldbelt is bordered by the lowlands of the Indus Basin. It is assumed that the folds terminate rather abruptly against the unfolded sediments below the Indus Plain.

2.24 Indus Basin

(FRIEDRICH K. BENDER)

The vast Indus Basin is located west of the Indian Shield. It extends for over 1,200 km from the Main Boundary Thrust in the north (Fig. 2.3) to the offshore area south of Karachi, east of the Murray Ridge (Fig. 7.10). To the west, it is bordered by the West Pakistan Foldbelt (see Chapter 2.23).

This region is not identical with the pre-collisional extension of the Indus Geosyncline. During Late Proterozoic and Paleozoic periods of time, the depositional pattern and environment of deposition of the sequences (TAHIRKHELI 1969, KHAN, M. A. 1969, TALENT & MAWSON 1982, DOLAN et al. 1987) indicate that the Geosyncline extended to the north and northwest far beyond the Main Boundary Thrust. This applies also for the Mesozoic through Palaeogene sequences in, and to the west and northwest of, the West Pakistan Foldbelt (Fig. 6.8, 6.10). The dominant depositional environments and the types of deposits in the Indus Basin in relation to chronostratigraphic periods, are summarized in Fig. 2.12.

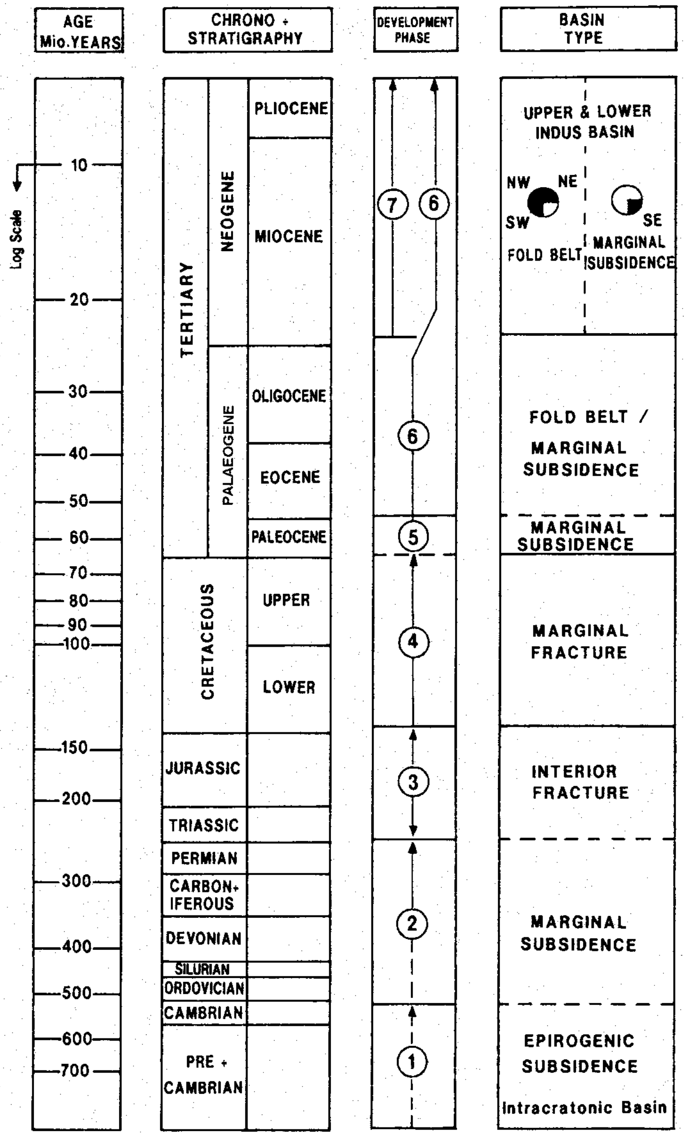


Fig. 2.12. Dominant depositional environment and type of the Indus Basin (modified after DOLAN et al. 1987, fig. 23).

Based upon differences in structure, sedimentary facies development, and chronostratigraphic sequences, the Indus Basin can be subdivided as follows (see Chapter 7.1):

- Upper Indus Basin, bordered by the Main Boundary Thrust in the north and the Sargodha High (swell) in the south (Fig. 7.1),
- Northern Lower Indus Basin between the Sargodha High and the Mari Khandkot High (swell),
- Central Lower Indus Basin south of the Mari Khandkot High to the southwestern margin of the Jacobabad High,
- Southern Lower Indus Basin and offshore area east of the Murray Ridge (Fig. 7.10) and west of the Naga Parkar High (swell).

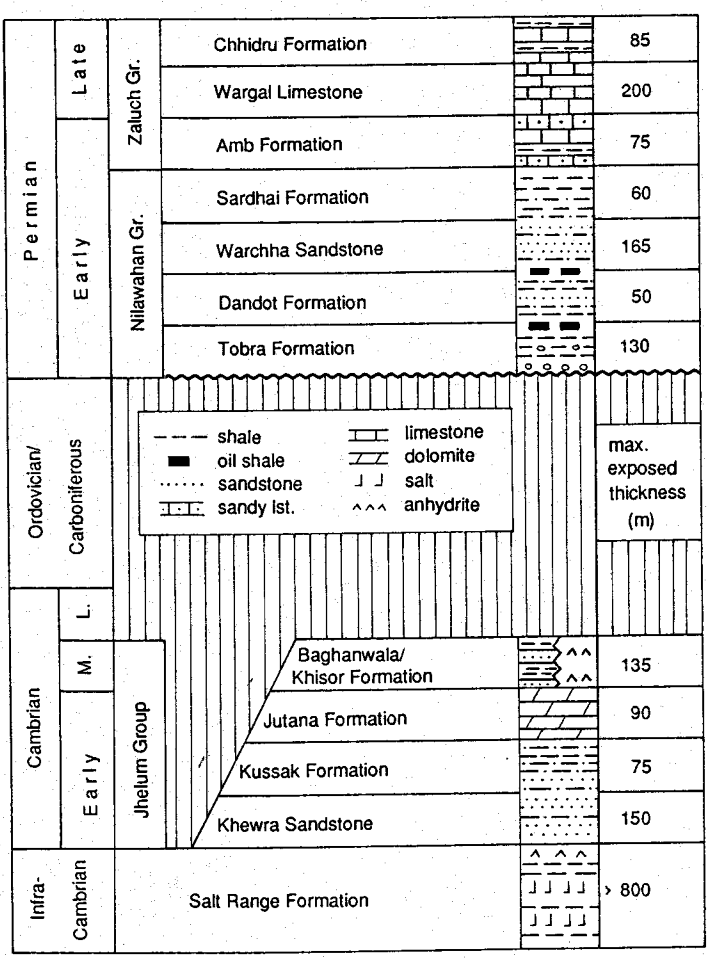


Fig. 2.13 A. Division of the Precambrian and Paleozoic sediments of the Upper Indus Basin (after PORTH & RAZA 1990 a, fig. 3).

The Upper Indus Basin is characterized by thick, non-metamorphosed sequences of "Infra Cambrian" and Cambrian age. These are separated from Permian sequences by a regional hiatus (Fig. 2.13 A; see Chapters 3.21, 3.24).

Mesozoic sequences (see Chapter 3.3), including three major transgressional unconformities, in the Lower Jurassic (Hettangian), Upper Jurassic (Oxfordian) and Upper Cretaceous (Cenomanian), have been defined as shown on Fig. 2.13 B (see Chapter 3.3).

The Cenozoic sediments of the entire Indus Basin are discussed in Chapter 3.4; those of the Upper Indus Basin are shown on Fig. 2.13 C, and of the Sulaiman Range and Foredeep on Fig. 2.14.

Sources of pelitic and clastic deposits in the Geosyncline since the Late Proterozoic were the Indian Shield and its structurally elevated Precambrian elements (see Chapter 5.21). Since the beginning of the Mesozoic, additional sources were the Highs (swells) within the Indus Basin (Fig. 7.1). During and after the collision of the Indo-Pakistan and the Eurasian Plates, the rising Himalayas and the West Pakistan Foldbelt were also sources of deposits (see Chapters 6.31, 6.32, 6.33).

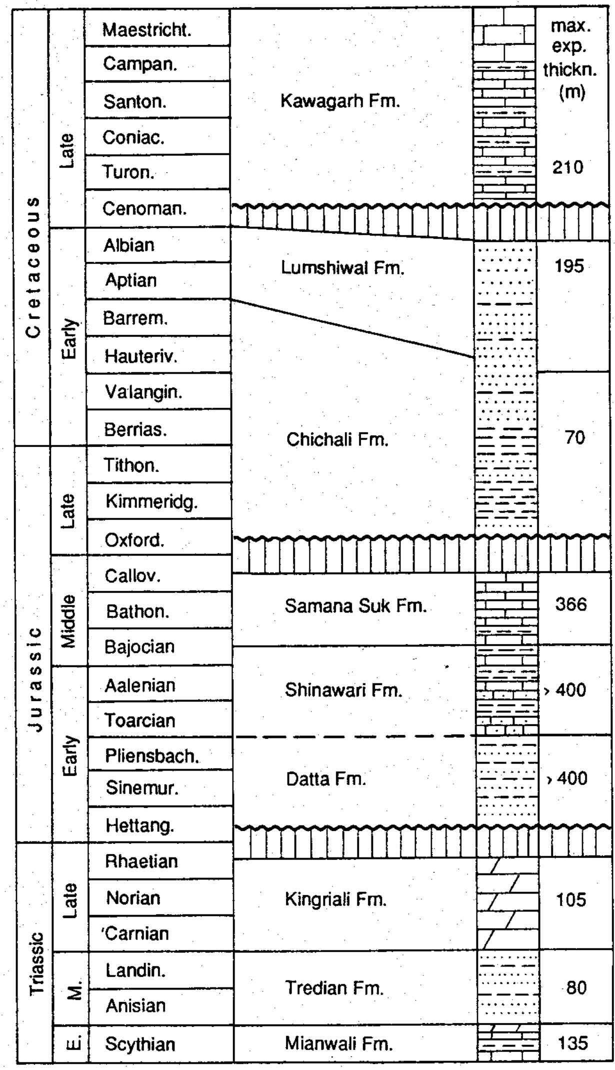


Fig. 2.13 B. Division of the Mesozoic sediments of the Upper Indus Basin (after PORTH & RAZA 1990 a, fig. 4); Legend Fig. 2.13 A.

Since the Oligocene, pelitic and clastic sediments were the main components of the sediments that accumulated in the Indus Basin. The marine environment began to retreat to the south until, early in the Pleistocene, the entire onshore Indus Basin served as a region of accumulation of pelites and clastics under terrestrial conditions (see Chapter 6.31). Very thick detrital material accumulated in the foredeeps south of the Himalayas and east of the West Pakistan Foldbelt, e.g. the Sulaiman Foredeep (Fig. 2.15).

2.25 The Tethyan Belt

(FAIZ AHMAD SHAMS)

The appearance of an eastward-widening triangular gap in the plate tectonic reconstruction of the Pangaea (SMITH & HALLAM 1970, BULLARD et al. 1985) confirmed the classical concept of the Tethys (DIETZ & HOLDON 1970), a Mesozoic sea that existed in

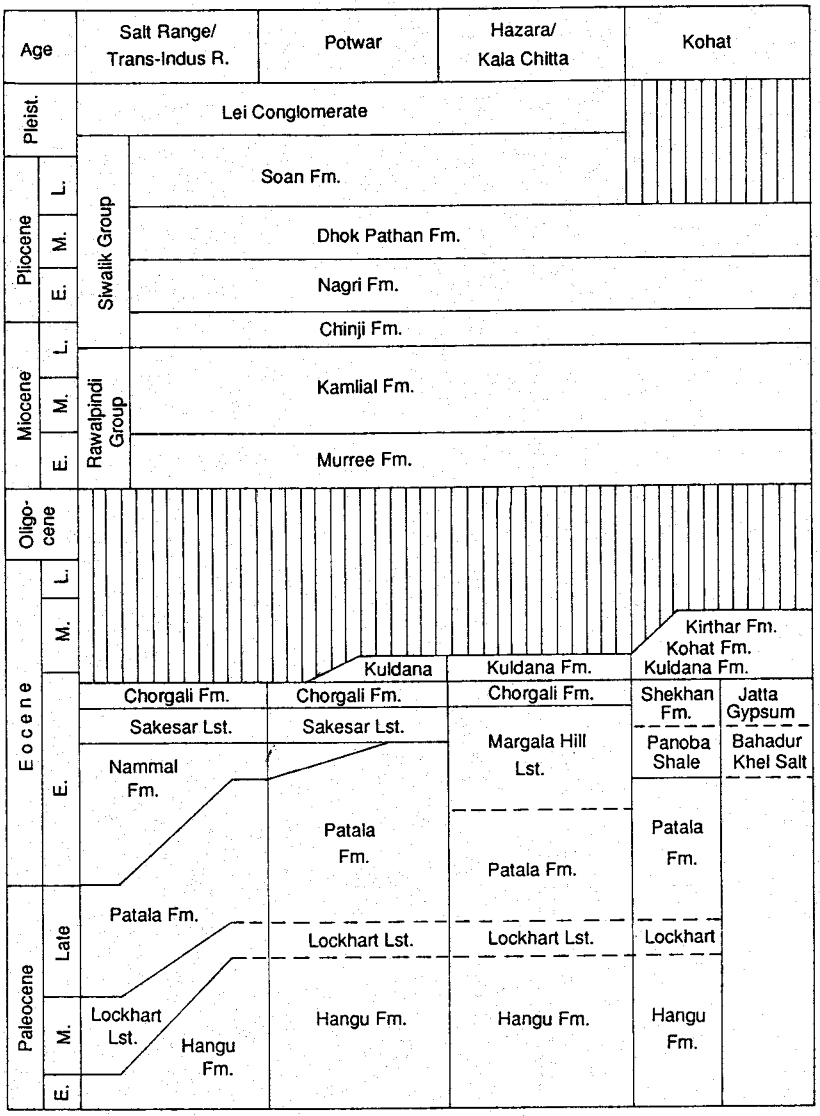


Fig. 2.13 C. Division of the Cenozoic sequences of the Upper Indus Basin (after PORTH & RAZA 1990 a, fig. 5).

the south of Eurasia and gave rise to the alpine-Himalayan Ranges (SUESS 1901, ARGAND 1924). More recent research has shown that the Tethys had two distinct realms; an older realm of the Palaeo-Tethys (Fig. 6.1) that gave rise to the Cimmerian mountain ranges in the north, and the Neo-Tethys (Fig. 6.4) that gave rise to the alpine Himalayan Ranges in the south (HSÜ 1977, HSÜ et al. 1978, SENGÖR 1981, 1984).

Of the 3,500 km-long Himalayas, northern Pakistan holds a small but important segment that represents the dynamic apex of the persistent anticlockwise rotation of the Indo-Pakistan Plate (POWELL 1979).

GANSSER (1964) subdivided the Himalayas into Sub-Himalayas, limited by the Main Frontal Thrust (MFT) and the Main Boundary Thrust (MBT), the Lower Himalayas, between the MBT and the Main Central Thrust (MCT), and the Higher Himalayas north of the MCT (Figs. 2.3, 2.4).

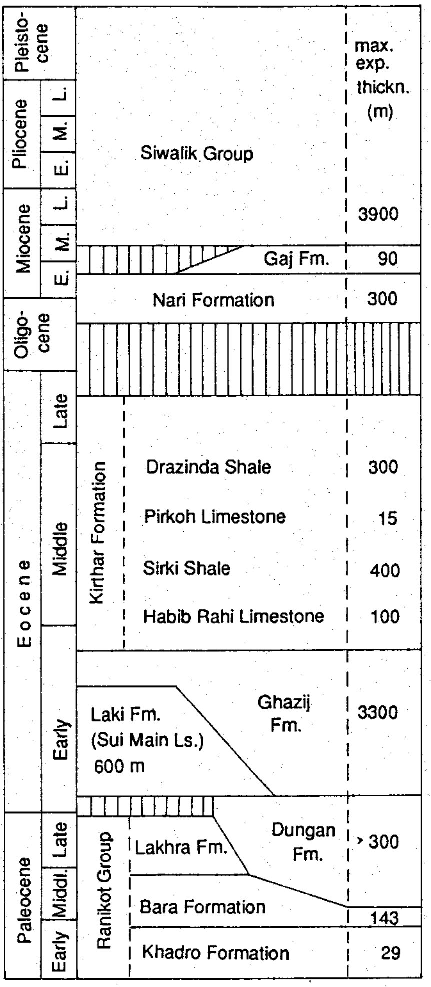


Fig. 2.14. Division of the Cenozoic sediments of the Sulaiman Range and Foredeep (after PORTH & RAZA 1990 b, fig. 3).

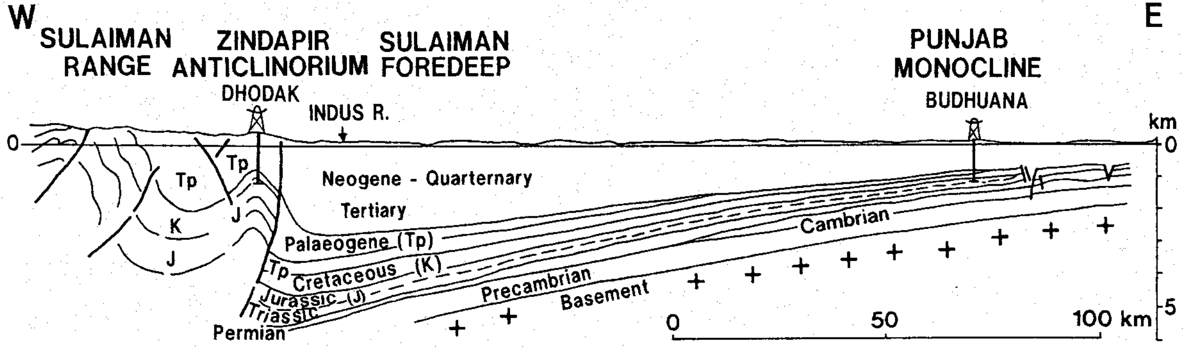


Fig. 2.15. Schematized cross-section Sulaiman Range-Sulaiman Foredeep-Punjab Monocline (after PORTH & RARA 1990 b, manuscript, fig. 4). J: Jurassic; K: Cretaceous; Tp: Palaeogene.

2.251 The Lower Himalayas

In northern Pakistan, the Lower Himalayas constitute the mountains of Azad Kashmir, east of the Hazara-Kashmir Syntaxis (HKS), and those of Hazara, Peshawar, Malakand, Dir and Mohmand.

The **Azad Kashmir Zone** is a north-south crescent-shaped territory, with the southern limits bordering the Sub-Himalayas and the northern parts including the Higher Himalayas. Notably, the Jhelum River Valley divides the Azad Kashmir Zone into a low-grade to unmetamorphosed terrane in the south from the high-grade metamorphic terrane in the north. The Pir Panjal Range, trending SSE and extending into India, is a prominent physiographic feature in the south with imbricated and overthrusted rocks between the MBT and the Panjal Thrust (PT). Towards north, however, a system of elongated domes and basins constitute anticlinal and synclinal structures with open folds. According to WADIA (1934), the entire Kashmir syncline moved southward along the low-angle PT; in Azad Kashmir, only the western fringes of the syncline are exposed.

Crossing the MBT northeast of Kahuta (33° 54'N; 74° 06'E), in Upper Haveli, Poonch District, the western flank of the Pir Panjal Range is composed of upthrusted shales, limestones and sandstones of Paleocene-Eocene age (Fig. 3.8; Patala Formation, Margalla Hill Limestone and Kuldana Formation) respectively, with inliers of the

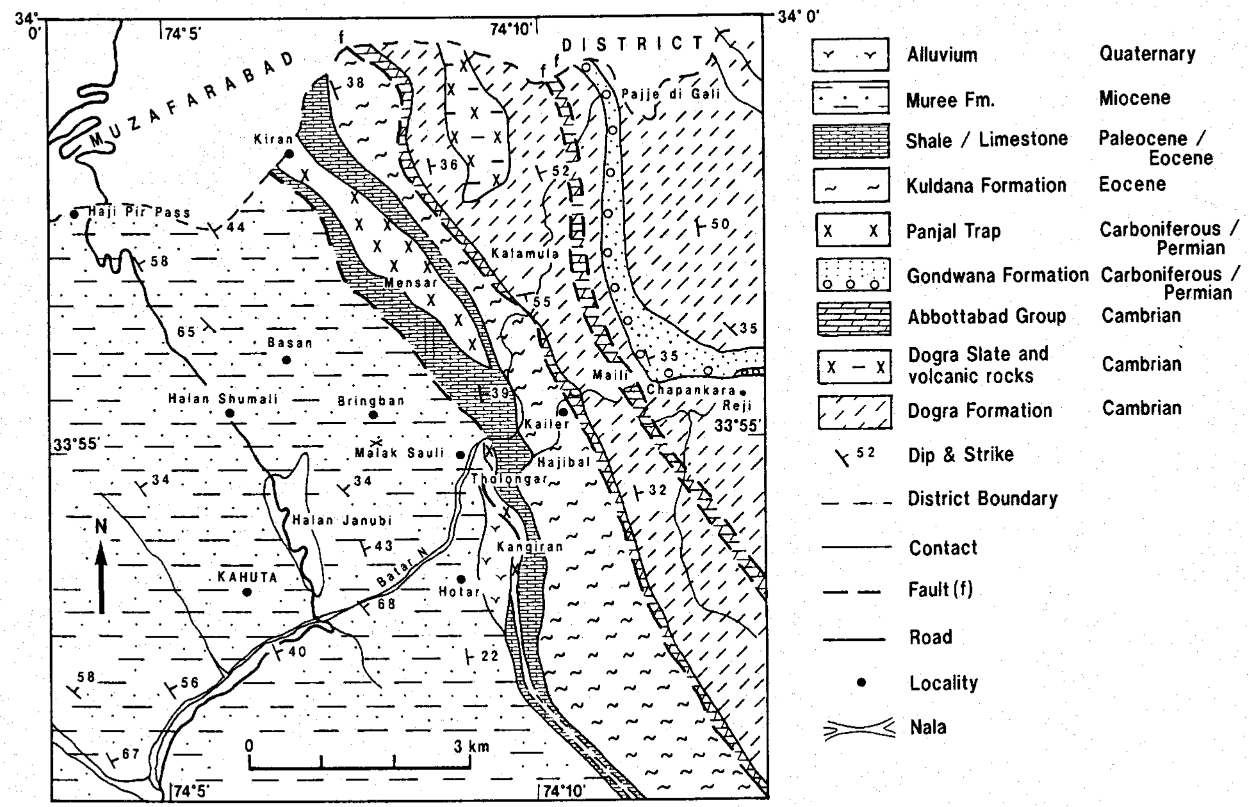


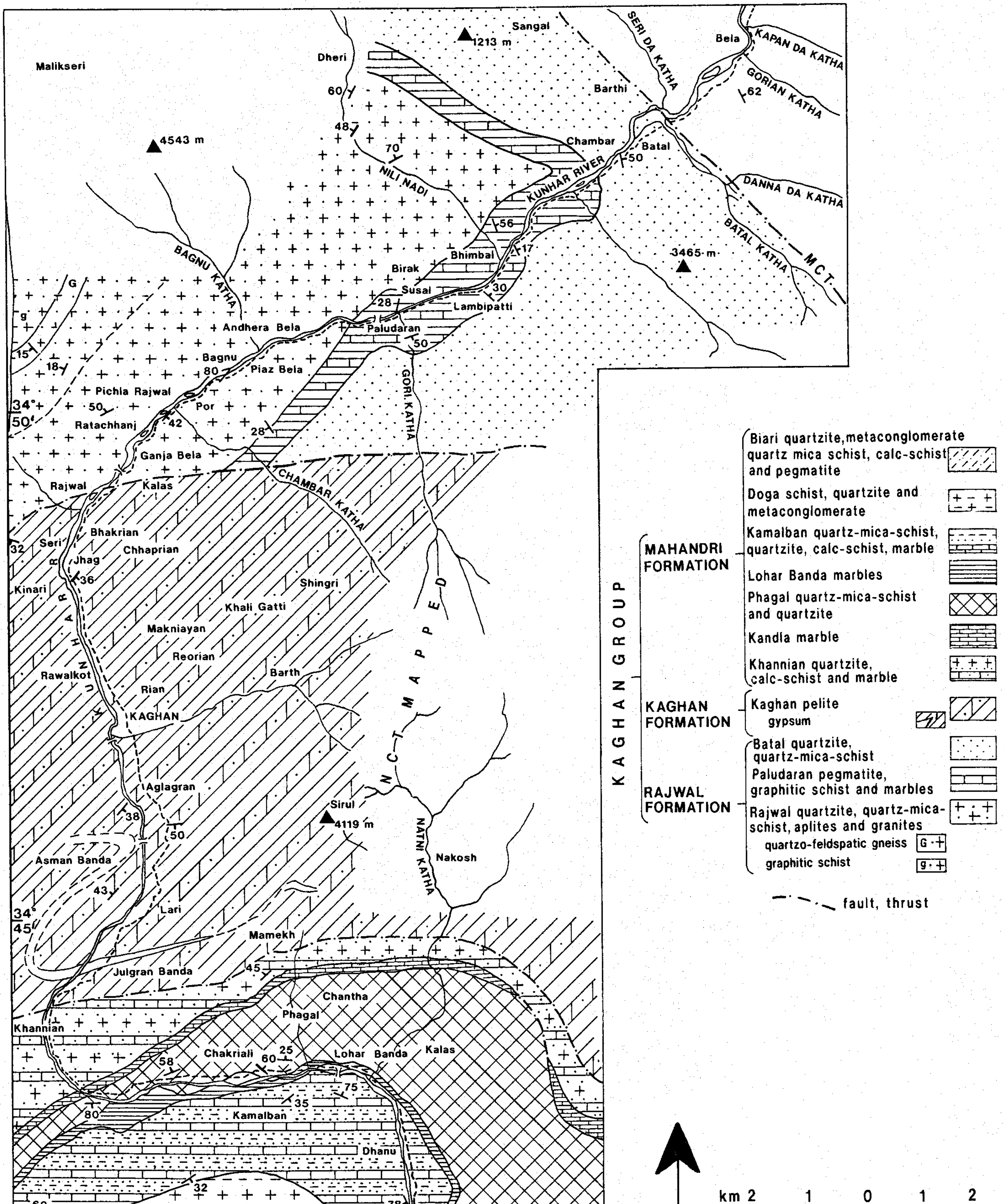
Fig. 2.16. Geological map of upper Haveli, Poonch District, Azad Kashmir (modified after CHAUDHRY & ASHRAF 1980, fig. 1).

Carboniferous-Permian Panjal Formation (CHAUDHRY & ASHRAF 1980) with NNW-trending outcrops (Fig. 2.16). The Panjal Formation (Fig. 3.2; MIDDLEMISS 1910) is composed of grey to black, agglomeratic to conglomeratic slates with ash and pyroclasts, succeeded by thick flows of basaltic and andesitic, massive to amygdaloidal lavas. Between Kailer and Maili, 15 m to 60 m thick bands of marble, calc-schists and quartzites (Cambrian Abbottabad Formation) (Fig. 3.2; see Chapter 3.21; LATIF 1974) are present as outliers within the Precambrian Dogra Slates (WADIA 1934). The latter cover extensive areas in the northeast. North of Chappankara and extending towards Paije-di-Gali, a conspicuous outcrop of Permo-Carboniferous Gondwana sediments is met, with basal meta-conglomerate (stretched quartz pebbles), and overlain by phyllites and flaggy quartzites (CHAUDHRY & ASHRAF 1984); elsewhere, plant fossils are known to occur within these beds (WADIA 1928).

In the Reshian area, Jhelum River Valley, the MBT is crossed east of Lamnian (34° 15'N; 73° 47'E), with the Panjal Formation upthrusted against the Murree Formation (Fig. 3.8) of Miocene age (RAHMAN & CHAUDHRY 1981, GRECO 1986). The Panjal Formation, consisting of volcanic greenstones, alternating with limestones and dolomites belonging to the Abbottabad Formation (Fig. 3.2). The Panjal Formation is limited in the northeast by the low-angle Panjal Thrust (PT) that separates mica schists of the Salkhala Formation (Fig. 3.2; WADIA 1934). Of the latter, GRECO (1986) mapped a sequence successively of mica schist, blue-grey marbles, quartz-garnet-mica schists, chlorite mica schists and phyllites, graphitic mica schists, garnet mica schists and quartzites, including a lensoid body of the Reshian augen gneiss. Layers of gypsum and calcareous gypsum inside the graphitic mica schist constitute an unusual lithology within the Salkhala Formation; these could have formed because of alteration of pyrite that is abundant in the schists (RAHMAN & CHAUDHRY 1981).

At Nauseri, east of Muzaffarabad, the MBT is crossed near the bridge over the River Neelum (or Kishenganga) where the Salkhala Formation is upthrust against the Murree Formation. The 1.6 km-wide outcrop of the Salkhala Formation consists of quartzitic schists, chloritic phyllites, graphitic mica schists, greenstones, amphibolites and marble, succeeded by a north-trending sheet of Late Precambrian Nauseri porphyritic augen gneiss (SHAKOOR 1976) about 2.1 km thick.

The northeast-trending Neelum River Valley from Tithwal to Kel cuts across the southern Salkhala syncline and the northern Kel anticline. A sequence of psammitic-pelitic metasediments (Kundalshahi-Nagdar schists, Authmuqam schists and phyllites and Loat quartzites) is exposed along the river upstream to Loat, intruded by granitic gneiss of Late Cambrian to Jurassic age with gradational contacts, and by the Neelum granite of Tertiary age with intrusive contacts (GHAZANFAR et al. 1981). Beyond Loat high-grade metamorphic terrane is exposed, formed of garnet mica schists, calc-schists and marbles, garnet-amphibole calc-gneisses, kyanite gneisses, graphitic gneisses and para-amphibolites, intruded by the Kel garnetiferous granitic gneiss (GHAZANFAR et al. 1981). These rocks represent two distinct lithologic sequences that, together or individually, do not appear to represent the Salkhala Formation of WADIA (1931); the lithology that has been ascribed to the Salkhala Formation is missing even at the type locality of Salkhala (34° 37'N; 73° 56'E), on the River Neelum. CHAUDHRY & GHAZANFAR (1990) claimed the Loat Fault to be the analogue of the Main Central Thrust (MCT) unknown in the Pakistan Himalayas sofar (Fig. 2.17).


Malikseri
4543 m
Dheri
Sangal
1213 m
Barthi
SERI DA KATHA
Bela
KAPAN DA KATHA
GORIAN KATHA
62
Chambar
Batal
50
KUNHAR RIVER
DANNA DA KATHA
BATAL KATHA
M.C.T.
3465 m
NILI NADI
60
48
70
56
17
Bhimbal
Birak
Susal
28
30
Lambipatti
BAGNU KATHA
G
g
Andhera Bela
Paludaran
50
15
18
Bagnu
80
Piaz Bela
GORI KATHA
34°
50'
Pichla Rajwal
50
Ratachhanj
Por
42
28
Ganja Bela
CHAMBAR KATHA
Rajwal
Kalas
32
Seri
Bhakrian
Chhaprian
Jhag
36
Kinari
KUNHAR
Shingri
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Makniayan
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Aglagran
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4119 m
38
50
NATNI KATHA
Nakosh
Asman Banda
43
Lari
34°
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45
Chantha
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60
25
Lohar Banda
Kalas
58
75
35
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Kamalban
Dhanu
32
60
42
78
82
53
68
70
40
Butan
50
Biari
Mahandri
Dohar
Chushal
Biari quartzite, metaconglomerate quartz mica schist, calc-schist and pegmatite
Doga schist, quartzite and metaconglomerate
MAHANDRI FORMATION
Kamalban quartz-mica-schist, quartzite, calc-schist, marble
Lohar Banda marbles
Phagal quartz-mica-schist and quartzite
Kandla marble
Khannian quartzite, calc-schist and marble
KAGHAN GROUP
KAGHAN FORMATION
Kaghan pelite
gypsum
Batal quartzite, quartz-mica-schist
Paludaran pegmatite, graphitic schist and marbles
RAJWAL FORMATION
Rajwal quartzite, quartz-mica-schist, aplites and granites
quartzo-feldspatic gneiss
G
graphitic schist
g
fault, thrust
N
km 2 1 0 1 2

The **Kaghan Valley Zone**, exposed west of the Azad Kashmir zone (Fig. 2.17), is high terrain, rising in altitude northeastwards to the Babusar Pass. Descending northwards to Chilas, the southern edge of the Kohistan Island Arc Complex is met that is bordered by the MMT zone (SHAMS 1975). CHAUDHRY & GHAZANFAR (1990) showed that the lithological framework of the Azad Kashmir Zone continues westwards into the Kaghan Valley. The Batal Fault was defined as the western continuation of the Loat Fault of the Azad Kashmir Zone (MCT of Pakistan Himalayas). The Salkhala terrane of WADIA (1931) is subdivided along the Batal Fault (MCT) into the Sharda Group (Fig. 3.2) area, north of the Batal Fault, and the Kaghan Group (Fig. 3.2) area, south of the Batal Fault. The Late Proterozoic Kaghan Group rocks (Fig. 2.17) constitute the Lower Himalayas in the Kaghan Valley Zone, consisting of the Rajwal Formation, including quartzites and quartz mica schists, graphitic schists and marbles, gneisses and granites; the Kaghan Formation (Fig. 3.2) composed of pelites and minor gypsum, and the Mahandari Formation including quartzites, meta-conglomerates, schists, and marble (CHAUDHRY & GHAZANFAR 1990). The rock sequences bend around the Hazara-Kashmir Syntaxis (HKS), generally attenuating on the western limb of the Syntaxis, following the MBT (BOSSART et al. 1984). West of the Syntaxis, the Hazara Block displays an arcuate structure, limited by the Panjal Thrust (PT) in the south; farther south to the MBT, the rock belts are only gently curved. As an analogue to the Hazara-Kashmir Syntaxis, the western limb of the Hazara Crystalline Zone is involved in the Indus Re-entrant (Fig. 2.6).

The Hazara sedimentary zone, south of the Panjal Thrust (PT) consists of Precambrian to Phanerozoic rocks, which are extensively exposed and swing southwestward to westward. The Late Proterozoic Hazara Formation (LATIF 1970, CALKINS et al. 1975, FUCHS 1975), 1,000 m to 2,000 m thick, is composed of cyclic units of current-bedded quartzitic micaceous sandstones, passing upwards to grey, fine- to medium-grained sandstones, siltstones and silty shales, now metamorphosed to slates or phyllitic slates (Fig. 2.18). Sedimentary structures show deposition in a flysch basin, although shallow water facies are also evident. Gypsum layers have been noted (LATIF 1970), and few beds of stromatolitic limestones (Miranjani limestone, Langrial limestone) are interbedded, such as at the Miranjani Hillock in the Nathiagali area, District Abbottabad, N W F P (GARDEZI 1968).

The Hazara Formation (Fig. 3.2; see Chapter 3.21) extends northward and tapers off as a wedge on the western limb of the HKS. Its comparable lithology is met in the Azad Kashmir Zone as WADIA's (1934) Dogra Slates. Covering wide country in the south, the Hazara Formation extends southwestwards and westwards. In the Gandghar Range, east of Tarbela, the Precambrian Manki Formation (Fig. 3.2), composed of argillites, shales and phyllites, has been correlated with the Hazara Formation (MICHAEL 1988). CRAWFORD & DAVIES (1975) reported 950 ± 20 mio years (Rb/Sr) whole rock age for the Hazara Formation.

The Hazara Formation is overlain by the Upper Proterozoic Tanawal Formation (Fig. 3.2), composed mainly of quartzose schist, quartzites and schistose conglomerates,

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Fig. 2.17. Geological map showing units of the Kaghan Group, central Kaghan Valley (modified after CHAUDHRY & GHAZANFAR 1990, fig. 1 c).

devoid of fossils. It is more than 1,000 m thick, and of continental arenaceous facies; at many places, arkosic components are prominent. The Tanawal Formation overlies directly the Salkhala Formation; in the Garhi Habibullah Khan area and near Abbottabad, the contact is gradational with the Hazara Formation, whereas the Tanawal Formation is missing at some locations. The Tanawal Formation is unconformably overlain by the Abbottabad Formation of Cambrian age (Fig. 3.2; LATIF 1974, CALKINS et al. 1975; see Chapter 3.21). The Abbottabad Formation consists of dolomites, quartzites and phyllites, with lithological and facies changes along the strike of the strata (SHAH 1977). Calcareous parts in the Abbottabad area contain a significant amount of phosphatic material (see Chapter 9.1; LATIF 1970, HUSSAIN et al. 1987). Extensions have

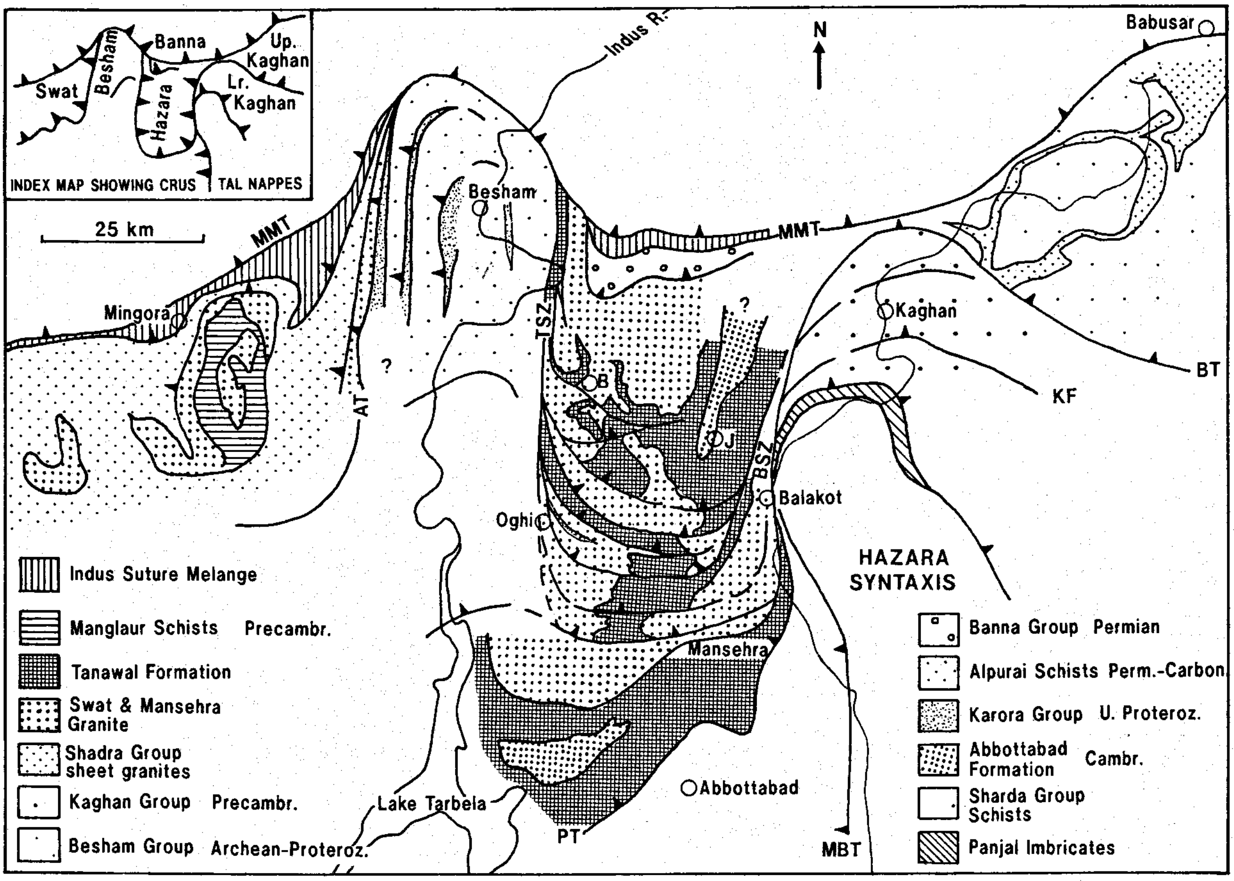


Fig. 2.18. Geological map of the Swat to Kaghan section of the Indo-Pakistan Plate within North Pakistan to show (inset) the locations of the major crustal nappes (after TRELOAR 1989, fig. 2 a). AT: Alpurai Thrust; B: Batagram; BSZ: Balakot Shear Zone; BT: Batal Thrust; J: Jabori; KF: Khannian Fault; MBT: Main Boundary Thrust; MMT: Main Mantle Thrust; PT: Panjal Thrust; TSZ: Thakot Shear Zone.

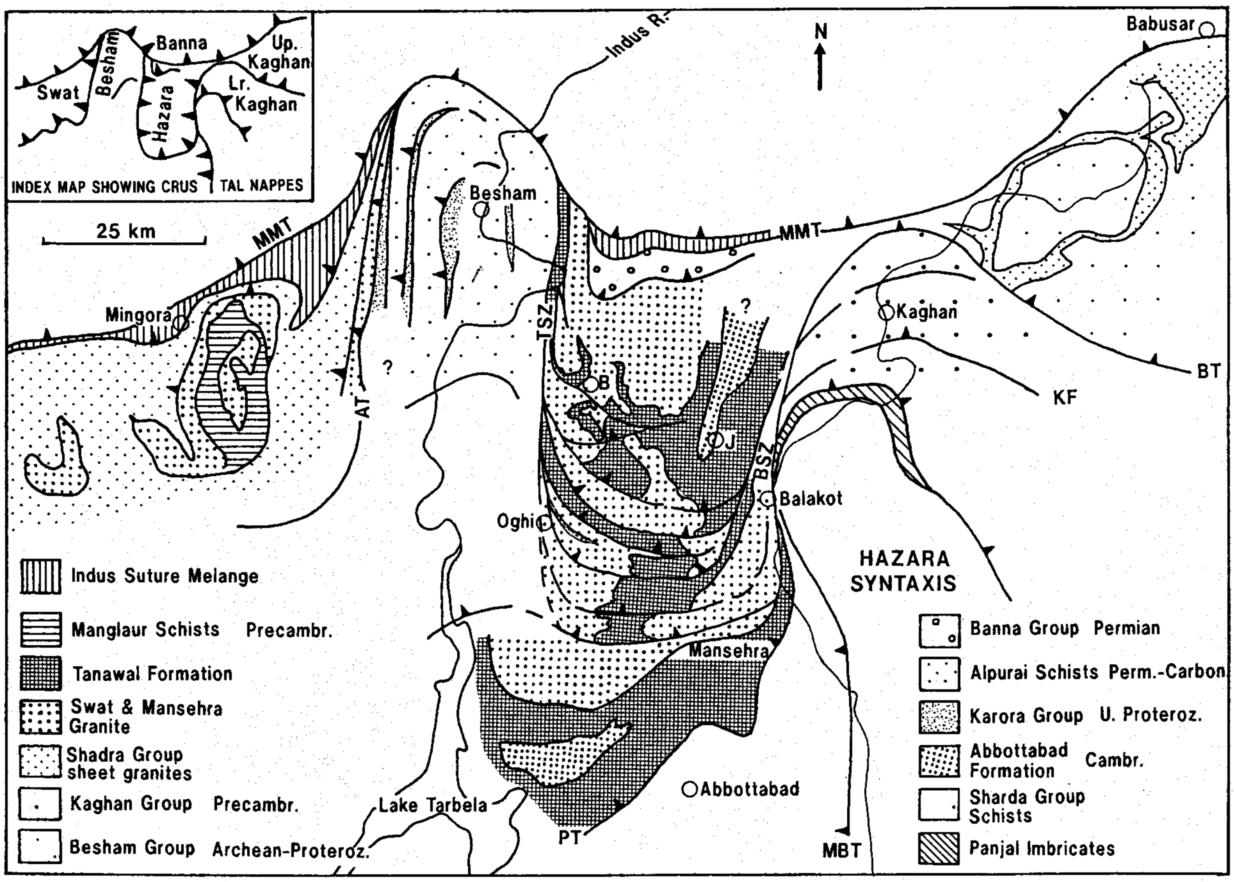
been found in the Sirban Hills, near Abbottabad, Garhi Habibullah, Kaghan Valley, Manda Kuchha, Jabori and Sherwan. In the Kachhi area (Fig. 2.18), the Abbottabad Formation (ALI 1962) has an unconformable contact with the underlying Tanawal Formation, marked by a boulder bed.

After the deposition of the Hazara Formation, the area was uplifted and a narrow trough developed in the northwest, where the Abbottabad Formation was succeeded by the Galdanian Formation of Cambrian age (GARDEZI & GHAZANFAR 1965; see Chapter 3.21). The rocks overlying the Abbottabad Formation belong to the Hazira Formation (Fig. 3.2) of Cambrian age (GARDEZI & GHAZANFAR 1965) with gradational contacts, and composed of grey and brownish calcareous siltstones and sandstones, and a few quartzitic layers; notably, the lower parts are glauconitic whereas the middle part is phosphatic; the glauconitic part contains remains of hyolithids (LATIF 1974).

The Gandghar Range, 50 km long and 13 km wide, extends southwestwards and separates the Indus River Valley at Tarbela from the Haripur Plain, appearing as a linkage between the Hazara and the Attock-Cherat Range. The Hazara Formation is represented by the Manki Formation (TAHIRKHELI 1970), with a succession of limestone (Baghdarra Limestone), quartzite (Tarpakhi Quartzite) and limestone (Pirthan Limestone). The strata continues into the Attock-Cherat Range, west of the Gandgarh Range and north of the Panjal Thrust (PT), with comparable lithologies divisible into three tectonic blocks, juxtaposed during the Paleozoic (TAHIRKHELI 1970, HUSSAIN et al. 1989).

The (1) **Hazara Crystalline Zone** extends from the Panjal Thrust (PT) in the south to the Main Mantle Thrust (MMT) in the north; it is bounded by the Balakot shear zone in the east and the Thakot shear zone in the west. The area is composed almost entirely of the Tanawal Formation (Fig. 3.2), including medium- to coarse-grained metaquartzites, micaceous metapsammites, meta-argillites, with rare metaconglomerate layers. The rocks show Barrovian-type metamorphism, progressively from chlorite grade in the south to sillimanite grade in the north. At Jabori, however, outcrops of the Abbottabad Formation are present extending in NNE direction. The Tanawal metasediments are intruded by thick sheets of the pophyritic Mansehra Granite. Beyond the Oghi Thrust, the granite is gneissic to mylonitic (Susalgali Gneiss) and appears to converge in metamorphic equilibrium with the adjoining metasediments to the extent of undergoing partial melting (SHAMS 1961, 1983, CALKINS et al. 1975). Rb/Sr whole rock age of the Mansehra Granite is 516 ± 16 mio years (LEFORT et al. 1980). TRELOAR (1989) identified six thrust nappes in the Hazara Crystalline Zone as a south-vergent stack. Each of the nappes is distinct stratigraphically and shows inversion of metamorphic grades because of the thrust-stacking about 25 mio years ago.

In the extreme north of the Hazara Crystalline Zone, south of the MMT, weakly metamorphosed rocks of the Banna Group (Fig. 3.2) of Permian age have been discovered (Fig. 2.18), composed of graphitic and non-graphitic pelites, calc-pelites and marbles, deposited over the high grade mylonites, gneisses and schists of the Tanawal Formation and the Mansehra Granite (WILLIAMS 1989). West of the Banna Group sequences (see Chapter 3.24), across the Thakot shear zone, the Besham area (Fig. 2.18) exhibits an antiform composed of gneisses, granites and metasediments (WILLIAMS 1989). The major part of the Besham area is underlain by Precambrian gneisses, schists, amphibolites, mylonites and undeformed microgranites identified as the Besham Group (Fig. 3.2). Unconformably overlying the Besham Group are the metapelites of the Karora Group of Late Proterozoic age (Fig. 3.2), metamorphosed to amphibolite facies; the unconformity is marked by a basal conglomerate with up to 10 cm thick clasts derived from the rocks of the Besham Group. To the east, the Tanawal Formation metasediments and the Susalgali Gneiss provide the basement to the overthrusted Banna devoid of fossils. It is more than 1,000 m thick, and of continental arenaceous facies; at many places, arkosic components are prominent. The Tanawal Formation overlies directly the Salkhala Formation; in the Garhi Habibullah Khan area and near Abbottabad, the contact is gradational with the Hazara Formation, whereas the Tanawal Formation is missing at some locations. The Tanawal Formation is unconformably overlain by the Abbottabad Formation of Cambrian age (Fig. 3.2; LATIF 1974, CALKINS et al. 1975; see Chapter 3.21). The Abbottabad Formation consists of dolomites, quartzites and phyllites, with lithological and facies changes along the strike of the strata (SHAH 1977). Calcareous parts in the Abbottabad area contain a significant amount of phosphatic material (see Chapter 9.1; LATIF 1970, HUSSAIN et al. 1987). Extensions have been found in the Sirban Hills, near Abbottabad, Garhi Habibullah, Kaghan Valley, Manda Kuchha, Jabori and Sherwan. In the Kachhi area (Fig. 2.18), the Abbottabad Formation (ALI 1962) has an unconformable contact with the underlying Tanawal Formation, marked by a boulder bed.



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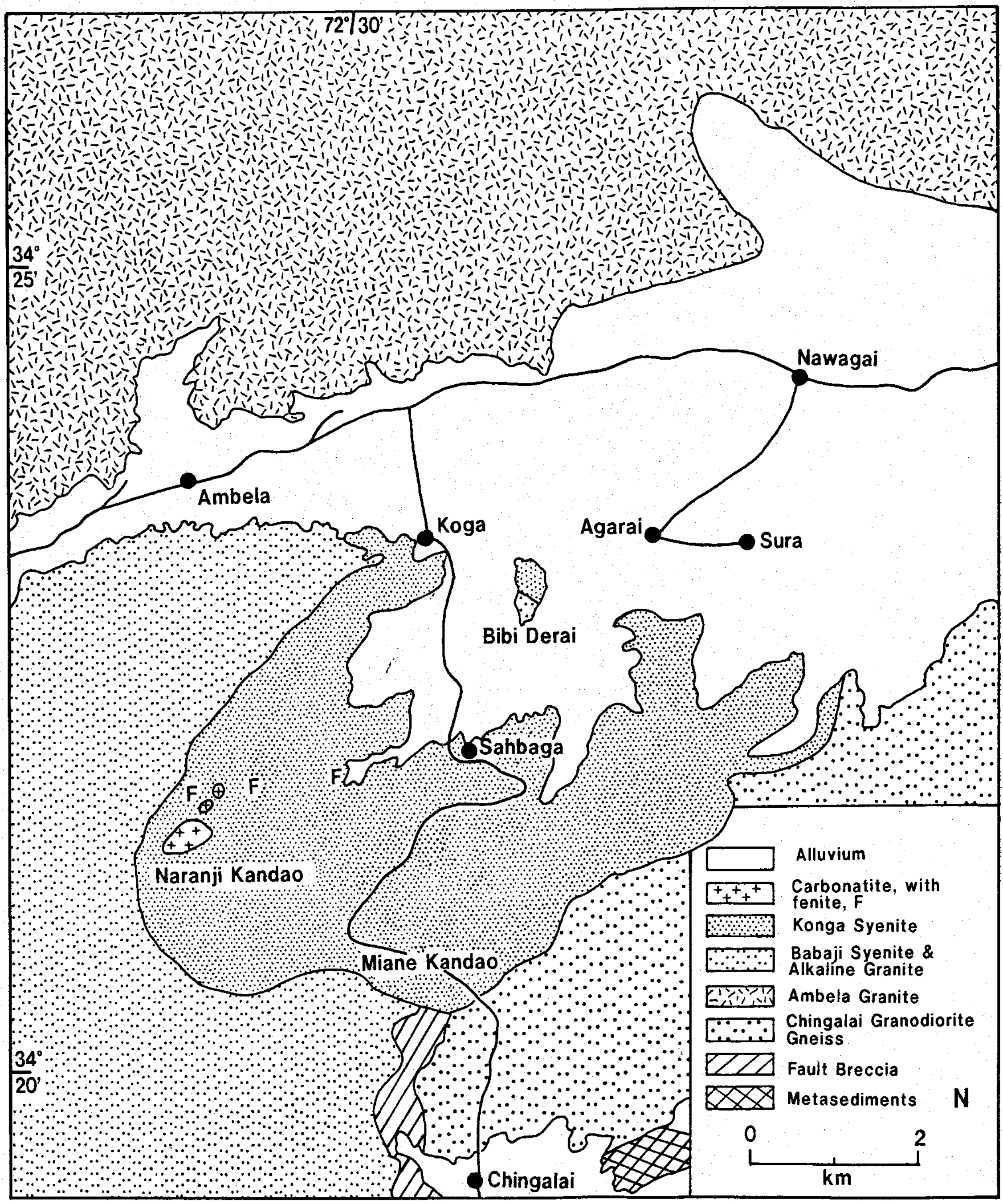


Fig. 2.19. Geological map of the Koga-Ambela-Utla area, Swat (after KEMPE 1983, fig. 10).

Group sequence, while in the west, the Manglaur Schist and the Swat Granite are the basement rocks that are covered by the Alpurai Schist up to the MMT zone.

The (2) **Swat Zone**, west of Besham remained a terra non-cognita for a long time, till MARTIN et al. (1962) published a first reconnaissance map. The three major lithologies of the area, Manglaur Schist (Late Proterozoic), Swat Granite Gneiss (Lower Cambrian) and Alpurai Group (Fig. 3.2), consist of thin north-south oriented wedge-shaped outcrops between Karora and Alpurai. The Manglaur Schist is composed of medium- to coarse-grained, quartzo-feldspathic garnet mica-schists, schistose gneisses, garnet amphibolites and pegmatites. These rocks are intruded by large sheets of the Swat Granite that compares with the Mansehra Granite to the east of the Besham area, including tourmaline-bearing sodic micro-granites (SHAMS 1983), and comparable in age ($^{40}Ar/^{39}Ar$ 515 mio years; JAN et al. 1981). According to KAZMI et al. (1984), the Manglaur Schist marks an unconformity, overlain by the Alpurai Group (Fig. 3.2) of rocks consisting of siliceous schists and calc-mica garnet schists. Gradationally, these schists are succeeded by Saidu Schist (Fig. 9.2; KAZMI et al. 1984) but at places, a basal conglomerate appears. The metamorphic grade ranges from greenschist to lower amphibolite facies. The Manglaur Schist can be correlated with the high-grade metamorphosed Tanawal Formation of the Hazara Crystalline Zone; therefore, its age is also Late Proterozoic, with a suspected Permian age of the Alpurai Group. The greenschists of the Saidu Schist intermingle tectonically with the MMT mélange zone at Mingora and elsewhere.

In the southern Swat Zone, the tectonic trends change from south southeast to southwest, but always with curvilinear traces of the fold axes. The relationship between the two tectonic zones is covered by alluvial deposits and the Ambela Granite (MARTIN et al. 1962). The latter is emplaced in the schists in the north and cuts all formations of the Swabi-Chamla sedimentary group in the south. The granite is thorougly coarse-

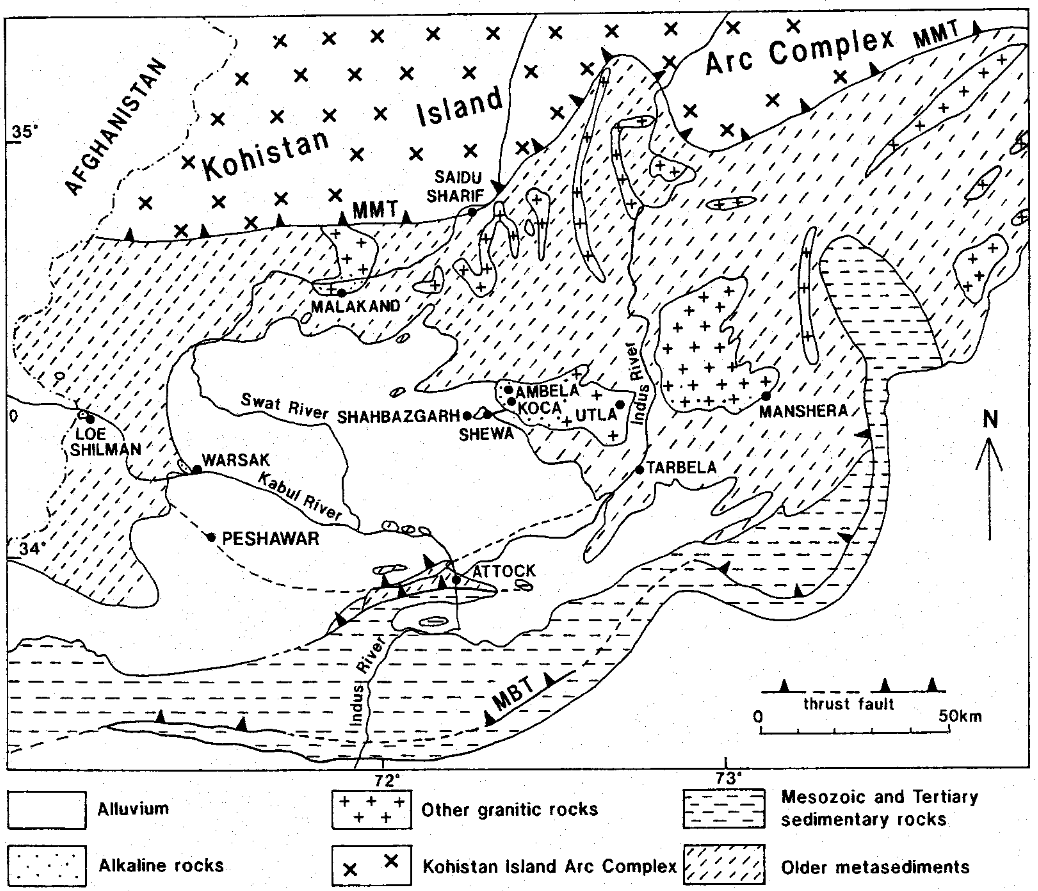


Fig. 2.20. Geological sketch map of the Peshawar Plain alkaline igneous province (after KEMPE 1983, fig. 1). MBT: Main Boundary Thrust; MMT: Main Mantle Thrust.

grained. The pluton is a composite body of oversaturated to undersaturated rocks, with younger basic intrusions (SIDDIQUI et al. 1968). The Koga Alkaline Complex (Fig. 2.19) of syenites, nepheline syenites and sodalite syenites hosts a body of Naranji Kandao Carbonatite with a zone of fenitization (CHAUDHRY et al. 1981). The ages range from 47.5 ± 1.5 mio years to 315 ± mio years (KEMPE 1973, MALUSKI & MATTE 1984, LEBAS et al. 1990).

Near the western tip of the Ambela Granite (Fig. 2.20), at Shewa-Shahbazgarhi, a composite complex of acid and alkaline porphyries forms small hillocks; the changes in the compositions indicate responses to compressional and extensional environments respectively (CHAUDHRY & SHAMS 1983).

Extensions of the alkaline rocks are present westwards (Fig. 2.20) at Warsak about 30 km WNW of Peshawar, as sills of alkaline granites with K/Ar age of 41 mio years (KEMPE 1973), ^{40}Ar/^{39}Ar age of 43.5 ± 5 mio years (MALUSKI & MATTE 1984); at Loe-Shilman, Khyber Agency as a sill occupying a fault zone with carbonatite of 31 ± 2 mio years age (LEBAS et al. 1990) and at Sillai Patti, about 35 km west of Dargai, as carbonatite complex with syenite and ultramafite (BUTT et al. 1989). KEMPE (1983) also considered some alkaline rocks at Tarbela and in Mansehra, claiming the existence of an alkaline province in the Peshawar area of the N W F P. JAN et al. (1981) considered also the Malakand Granite as a member of the Peshawar Plain alkaline province but the age of 23 ± 2 mio years (^{40}Ar/^{39}Ar, MALUSKI & MATTE 1984) does not justify it, in addition to the calc-alkaline nature of the Malakand Granite (HAMIDULLAH et al. 1986). SHAMS (1983) considered those to be the evolutionary products of the reconstituted and remobilized basement complex of the Indo-Pakistan Plate.

The (3) **Dir-Mohmand Zone** shows a continuation of various formations as belt-like outcrops with comparable lithologic and stratigraphic positions. In the Shamozai area, Districts Swat and Dir, argillaceous schists metamorphosed up to kyanite grade are present, with marble, and greenschist adjoining the MMT mélange zone in the north (SHAMS et al. 1983). Farther west, the southern Dir District is occupied by calc-schists, garnet mica schists, graphitic schists and quartzose schists (CHAUDHRY et al. 1976), the

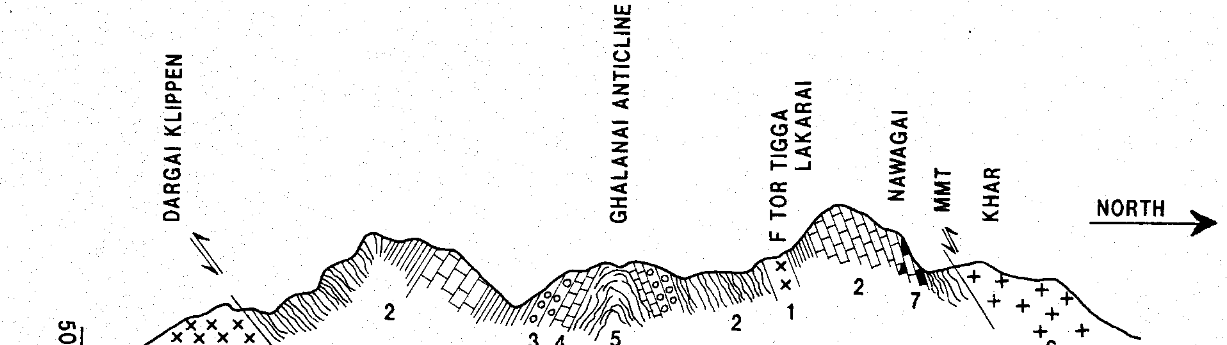


Fig. 2.21. Diagrammatic cross-section Mohmand, Malakand and Dir (after THAHIRKHELI 1979). 1) Dargai Ultramafites; 2) Metasediments; 3) Quartzite; 4) Dolomite; 5) Metasediments older than 2) metamorphosed to kata-grade; 6) Amphibolite; 7) Volcanites, Mafites-Ultramafites.

metasediments are considered to be of Precambrian to Cambrian age (KEMPE 1983). Metamorphic grades are normally developed.

The Dir and Mohmand Zone farther west extends to the Afghanistan border. A thick metasedimentary sequence of graphitic, quartzose and mica schists metamorphosed up to staurolite grade, is present, along with medium-crystalline dolomitic limestones and interbedded phyllitic slates, intruded by dolerites, granites, pegmatites and quartz veins. The whole sequence is thrust over the Dargai ultramafites. A notable lithologic sequence is seen in the Ghalanai Anticline in the Mohmand area (Fig. 2.21). With a core composed of schistose rocks and limestone bands, with acid and basic intrusions, the anticline is covered with thin-bedded dolomites, thin-bedded friable calcareous quartzites, and with the outer blanket of phyllitic schists (TAHIRKHELI 1979). In the Jandul Valley, metasediments are in direct contact with the MMT zone, where amphibolitic rocks are developed with amphibole schist and greenschist (KAKAR et al. 1971, SAIF 1971, BADSHAH 1979); these rocks might continue into Afghanistan.

2.252 The Higher Himalayas

Although GANSSER (1964) described the Nanga Parbat Massif as belonging to the Higher Himalayas, the extent of its regime could be delineated only after location of the Main Central Thrust (MCT) in the Pakistan Himalayas (CHAUDHRY & GHAZANFAR 1990), the Loat Thrust in the Azad Kashmir Zone and its westward continuation as the Batal Thrust in the Upper Kaghan Valley (Figs. 2.3, 2.4).

The Nanga Parbat Massif (8,126 m) and its twin, the Haramosh Massif (7,397 m), constitute a unique NNE-trending orographic feature in northern Pakistan; the orogen strikes against the WNW trend of the Karakorum in the north, forming a prominent syntaxial structure northeast of the Hazara-Kashmir Syntaxis (HKS). North of the Loat-Batal Thrust (MCT), the region is occupied by rocks of the Sharda Group (Fig. 3.2; previously Salkhala Formation) of Precambrian age (see Chapter 3.21) including calc-pelitic gneisses, pelitic gneisses, graphitic gneisses and marbles, with sheet granites, migmatites and younger garnet-tourmaline granites and amphibolites. The Sharda Group is overlain in the southeast by Cretaceous-Eocene volcanics (WADIA 1933, CHAUDHRY & GHAZANFAR 1987). MISCH (1949) showed the presence of a progressive metamorphic sequence from low grade to highest grade, leading to granitization that culminated in the formation of the central granitic gneiss dome of the Massif (Fig. 2.22). SHAMS et al. (1979) showed that the granitization was caused by alkali metasomatism that depended on the specific lithologic composition of the metasediments involved. The younger tourmaline-bearing granites and aplites are considered as an end product of the granitization. Thus, the Massif presents an example of the close relationship between progressive metamorphism and synkinematic granitization.

The Shengus and Iskere gneisses (Fig. 3.2) of the Nanga Parbat-Haramosh Massif show U/Pb ages of 2,300 to 2,500 mio. years (ZEITLER et al. 1989), thus indicating the continued tectonic-metamorphic history. The orogen is presently undergoing uplift at an average rate of 5 mm/year (ZEITLER 1985), generating mass movements on the unstable slopes (BUTLER et al. 1988).

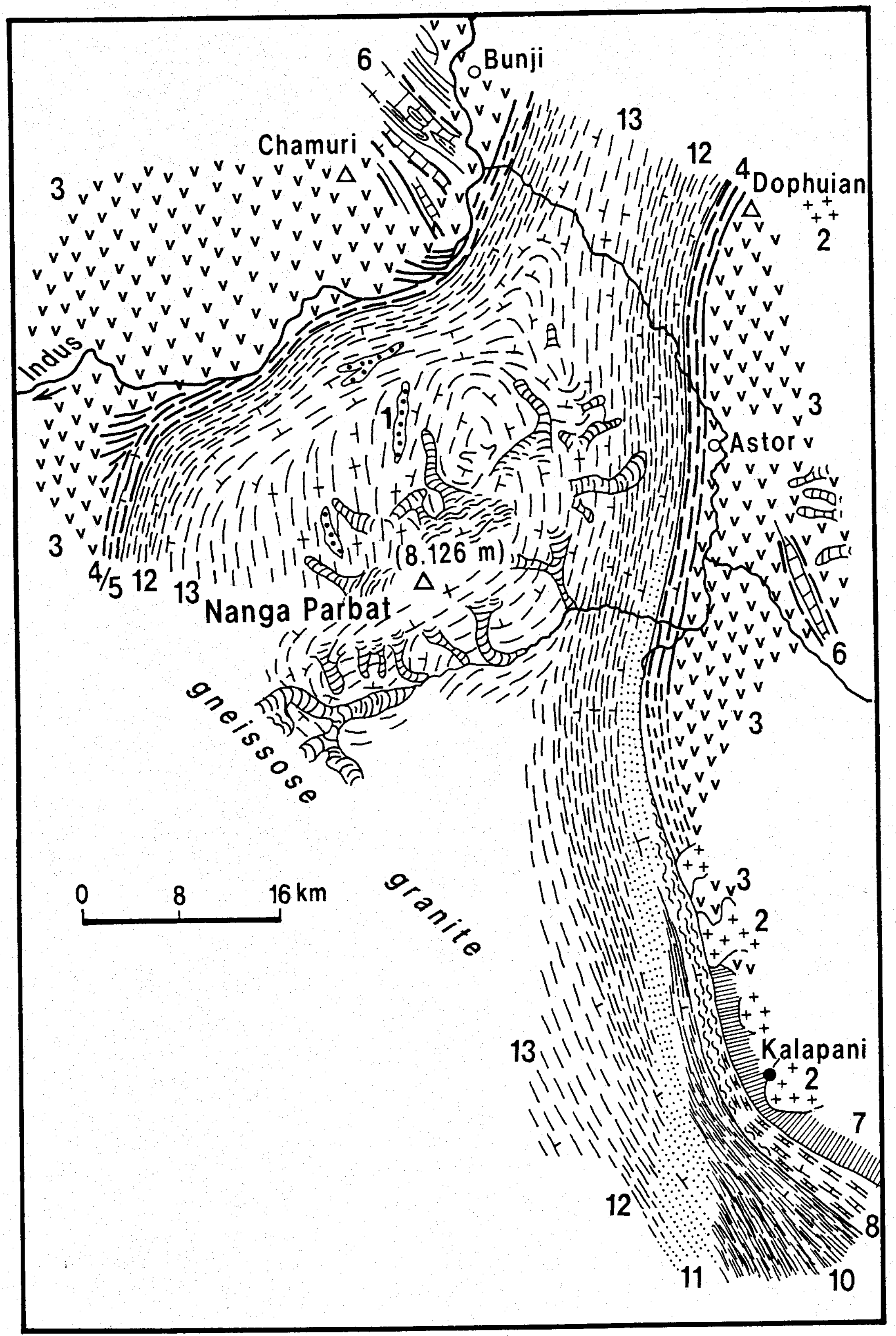


Fig. 2.22. Geological sketch map of the Nanga Parbat area (after MISCH 1949, page 61).

1	tourmaline granite; post-orogenic (dotted)	
2	quartz-diorite and granodiorite; post-norite	
3	norite, hypersthene diorite, etc.; widely altered to metanorite and metadiorite; Eocene	
4	mesozonal amphibolite, synorogenic-metamorphic	
5	epizonal greenschist, norite, etc.	
6	marble and schist zones in norite, metanorite, etc.	
7	basaltic and more acidic lavas	
8	variegated tuff breccias and tuffaceous-calcareous argillites	Createceous-Eocene volcanic formation
9	tuffaceous argillaceous rocks (8) epizonally metamorphic	
10	Salkhala group; dark slates and phyllites with subordinate thin limestone and greenstone bands	
11	non-granitized schists; chiefly mesozonally metamorphic Salkhalas	metamorphism and granitization synorogenic
12	mesozonal migmatitic gneisses (chiefly augen gneisses and banded gneisses); incompletely granitized Salkhalas	
13	migmatic granitic gneiss; granitized Salkhalas (11)-(13) contain intercalations of schists, marbles, and amphibolites; mesozonal in (11) and (12), katazonal in (13)	

2.253 The Kohistan Island Arc Complex

While presenting the first geological map of the Swat Himalayas, MARTIN et al. (1962) described the existence of a regional tectonic thrust along which their (northern) upper Swat hornblendic group rocks were upthrusted against the (southern) lower Swat-Buner schistose group rocks. The importance of this thrust was realized on the discovery of blueschists from near Topsin, upper Swat (SHAMS 1972) that lent support to the concept of continent to continent collisional origin of the Himalayas (DEWEY & BIRD 1970, POWELL & CONAGHAN 1973), and the recognition of a fossil island arc (DESIO 1977, TAHIRKHELI et al. 1979, GANSSER 1980, HONNEGAR et al. 1982), now called the Kohistan Island Arc.

The borders of the Kohistan Island Arc Complex are shown on Fig. 2.23. To the west, the arc complex closes towards Afghanistan ("western domain"); to the east, east of the Nanga Parbat Syntaxis, it extends to the Deosai and Ladakh (mostly in India) areas ("eastern domain").

To the south, the Main Mantle Thrust (MMT) separates the Arc Complex from rocks of the Indo-Pakistan Plate; to the north, the Main Karakorum Thrust (MKT) separates the Arc from rocks of the Eurasian Plate. The Arc Complex consists of calc-alkaline plutonites and volcanics, metasediments, granulites and amphibolites. The MMT and MKT are narrow lithotectonic zones that are characterised by outcrops of metavolcanics and ophiolitic mélanges that record suturing of the Arc to the Indo-Pakistan Plate in the south and the Eurasian Plate in the north.

A generalized sequence of geologic formations and structures from south to north in the Kohistan Island Arc Complex is described below:

No blueschist has been reported from the Deosai area east of the Nanga Parbat although blueschist facies rocks have been described from Sumdo (33° 10'N; 78° 31'E) in Kashmir-Ladakh (VIRDI et al. 1977).

2.253.2 Amphibolite Belt

The Amphibolite Belt enters Pakistan from eastern Afghanistan. It bifurcates in the area of southern Dir, N W F P, into a Southern and a Northern Amphibolite Belt (CHAUDHRY et al. 1976), enveloping the vast Chilas mafic-ultramafic complex (see Chapter 4.12) before joining together south of Bunji, Northern Areas, west of the Haramosh Massif. A single, relatively small amphibolite belt extends along the eastern flank of the Haramosh Massif.

The **Southern Amphibolite Belt** consists of a large variety of igneous rocks of intermediate to ultramafic composition, although amphibolite s. str. constitutes only about 25 % of the rocks in the Belt. The igneous rocks have gradational contacts and contain xenoliths and screens of amphibolites. Nevertheless, hornblende is ubiquitous and commonly is the dominant mineral, permitting a subdivision into mappable leuco-amphibolites and mela-amphibolites (CHAUDHRY et al. 1974a).

In southern Dir, N W F P, CHAUDHRY et al. (1974a, 1976) mapped a diorite body about 9 km wide separating the Southern from the Northern Amphibolite Belt; a norite body intrudes both the amphibolite and the diorite. Tonalite, hornblendite and quartz porphyry rocks are present as mappable units. About 10 km north of Shah Dheri, upper Swat (ASHRAF et al. 1969), and Taghma area, 20 km north-east of Mingora, upper Swat (ZULFIQAR 1976), granodiorite bodies are observed that intrude the amphibolites. CHAUDHRY et al. (1974) mentioned screens of eclogites and ZULFIQAR & SHAFEEQ (1974) described a body of spinel lherzolite from Bar Bandai, upper Swat.

East of Swat and across the Indus Valley, the Southern Amphibolite Belt widens to nearly 50 km, but becomes progressively smaller again towards Babusar, southwest of the Nanga Parbat peak. SHAMS (1975) described a 25 km-wide diorite body intruded by the Chilas mafic-ultramafic complex. Towards south, the diorite is followed by chlorite orthogneiss, chlorite gneiss, biotite-chlorite gneiss, garnet-epidote amphibolite, and a thick band of amphibolite containing a folded peridotite lens.

In places hornblendites represent large intrusive bodies within the Amphibolite Belt (e.g. Jandul Valley, western Dir, KAKAR et al. 1971). The rock body of the Jandul Valley is followed southwards by inter-layered pyroxene diorite, hornblende pyroxenite and hornblendite, passing into amphibolites. Quartzite bands appear in the Jandul Valley (KAKAR et al. 1971), and calcareous material at Patan, Allai Kohistan (JAN 1979), south of Sassi (35° 52'N; 74° 45'E) and north of Chilas (TAHIRKHELI 1982). BUTT (1983) has shown that the ultramafic bodies associated with the amphibolites are not an alpine-type suite but represent komatiitic affinities. Association of volcanic tuff, glass and cryptocrystalline material has been described by SHAMS et al. (1983) from the Shamozai area, Swat/Dir border, N W F P, whereas pillow structures have been mentioned by BUTT (1983) from higher topographic levels in the amphibolite belt. Ultramafic igneous breccia appears at Butto Gah, along with fragments of dunites and peridotites, in a matrix of fine-grained ashy material containing calcite; BUTT

(1983) interpreted this as "flow-top" breccia. Thus an igneous origin of the Southern Amphibolite Belt has been generally accepted.

BARD et al. (1980) proposed that banding in the amphibolites was produced by three processes: Metamorphic differentiation along numerous shear zones almost parallel to the foliation; veins and veinlets of early injections of leucocratic melts transposed into the foliation; inherited layering of possible volcano-sedimentary origin (tuffs and tuffites). According to JAN (1979), however, the amphibolites of the Southern Belt are prograde metamorphic products of mafic to intermediate magma intruded into tuffs, with some volcanic flows, the tuffs now represented by banded amphibolites.

The **Northern Amphibolite Belt**, or the northern branch of the parent Amphibolite Belt, was given this status from Dir, N W F P, by CHAUDHRY et al. (1974a). Previously, DESIO (1964) and GANSSER (1964) had briefly described the amphibolitic rocks exposed between Thalichi and Bunji, Northern Areas, while BARD et al. (1980) showed the presence of an amphibolite layer north of the Chilas mafic-ultramafic complex, representing the Northern Belt.

The Northern Amphibolite Belt branches off from southwest of Dir in a northeasterly direction. Crossing the Panjkora River, its major northern part is truncated against the western terminus of the Chilas Complex, which separates it from the Southern Amphibolite Belt by a wedge-shaped southwesterly extension. The Panjkora River section exposes the thickest part of the Northern Belt, about 15 km wide. Southeast of Dir, the Belt becomes rather thin and crossing the (upper) Swat River, south of Kalam, almost disappears in southern Kohistan. It reappears in mappable thickness north of Chilas and extends eastwards.

The northern amphibolites are in general more banded, commonly appearing as striped amphibolites (BARD et al. 1980). CHAUDHRY et al. (1974b) recognized banded, foliated and layered amphibolites that were further classified into epidote amphibolites, plagioclase amphibolites and garnet amphibolites, in the Timurgara-Lal Qila area of the Dir District. Peculiar pyroxene-quartz-garnet dykes cut the amphibolites as discordant intrusions. Garnet amphibolites are mostly developed near the contacts with noritic intrusions that hold xenoliths of, and extend apophyses into the amphibolites. Like the Southern Amphibolite Belt, large rock bodies of dioritic composition are present with intrusive contacts and also contain xenoliths and schlieren of amphibolites.

CHAUDHRY et al. (1974) proposed the origin of the northern amphibolites by metamorphism of the calcareous formations. Nummulites and *Assilina* have been discovered from the marly portion of the calc-schist.

Locally, the northern amphibolites display igneous textures and flow foliation, especially where they have escaped tectonic deformation. In such outcrops, particularly in the upper portions of the Amphibolite Belt, pillowed metabasalts are recognizable (BARD et al. 1980). COWARD et al. (1986) suggested that the amphibolite belts do not represent an oceanic crust, but are highly deformed and recrystallized belts of arc-type plutonics, metasediments and metavolcanics.

2.253.3 Jijal-Chilas Igneous Complexes

The Jijal-Chilas Mafic-Ultramafic Complexes represent highly metamorphosed sequences of mafic-ultramafic rocks (Fig. 2.4). According to COWARD et al. (1982, 1986), these complexes enclose a regional geosyncline that is now occupied by the Southern Amphibolite Belt whereas the Northern Amphibolite Belt overlies the north-dipping northern part of the Chilas Complex.

The Indus River section between Jijal and Patan (33° 01'N; 74° 18'E), Allai Kohistan, N W F P, exposes a complete section of the 200 km² **Jijal Complex**. In the south, the complex abuts against the Indo-Pakistan Shield rocks without intervention of the MMT Zone, probably sliced off during intense shearing. Its northern margin has a faulted contact with the Southern Amphibolite Belt.

The **Jijal** Complex is a composite mass of a northern belt of garnet granulites and a southern belt of alpine-type ultramafites. The original rocks of the granulite portion consist of noritic gabbros, with less abundant pyroxenites, troctolites, olivine gabbros, websterites, feldspathic allivalites and hypersthene quartz diorites.

The ultramafic rocks of the Jijal Complex form a north-dipping belt-like body over 4.5 km wide along the southern part of the granulite mass. The ultramafic rocks are composed of peridotites, with subordinate pyroxenites, harzburgites and dunites (JAN 1979b). Serpentinization is not very intense except along the southern margins and along shear planes within the main ultramafic body. In the basal part of the rock body, chromite lenses are found in the layered portions, and magnetite concentrations forming as much as 20 % of the rock are present in the serpentinized dunites and peridotites (ASHRAF et al. 1980).

The **Chilas** Mafic-Ultramafic Complex of the Kohistan Island Arc is about 300 km long between the Nanga Parbat in the east and the Dir District in the west, and is about 40 km wide in its central part. On the eastern side of the Nanga Parbat, the Complex occupies a strip as much as 15 km wide trending north, and pinches out west of the Burzil Pass (34° 31'N; 76° 12'E), India. Many isolated studies of the Chilas Complex were reported (WADIA 1932, MARTIN et al. 1962, JAN & MIAN 1971, JAN & KEMPE 1973, CHAUDHRY et al. 1974) before its belt-like configuration was recognized (SHAMS 1975) and incorporated in the plate tectonic model of the northwest Himalayas (COWARD et al. 1982, BARD et al. 1983). This Complex is considered as the root of the Kohistan Island Arc, with its deepest part exposed in the Chilas (33° 26'N; 74° 06'E) area, District Diamir. The southern margin of the Complex is intrusive into the amphibolites of the southern belt but at places, such as Jal, Soe and Fatehpur in Upper Swat, it is in contact with garnetiferous calc-silicate rocks. Its northern margin is mostly amphibolitized and adjoins diorite intrusions; it intrudes into schists near Bunji along the River Indus and carries marble xenoliths near Astor on the eastern flank of the Nanga Parbat (CASNEDI & EBBLIN 1977, JAN 1980).

The rocks of the Chilas Complex are composed dominantly (> 80 %) of norites, with subordinate troctolites, pyroxenites, anorthosites, hypersthene quartz diorites, olivine-rich ultramafics and mafic to ultramafic pegmatites (SHAMS 1975, JAN et al. 1984, KHAN et al. 1989). Norites range from completely massive to flow-foliated and banded varieties. Foliation is always primary and is marked by the alignment of coloured minerals, mineral schlieren and rhythmic banding of light and dark coloured bands from a few mm to over 2 m thick. At places, more than 60 fine-scale layers in a m-thickness of rock were identified (JAN et al. 1984). Near the contact with the diorites of the Amphibolite Belt, a hornblende-plagioclase pegmatitic rock is common in the norite mass, giving rise also to sizable hornblende-gabbro bodies, such as near Singal. As a result of progressive increase in pyroxene content, peridotites developed as marginal zones around the dunite bodies, occurring also as xenoliths inside norite, such as about 1.5 km south of the River Indus, near Chilas. Pyroxenites occur mostly as joint-filling material inside the dunites, such as east of Chilas, and as xenoliths inside the norites; in some places, the pyroxenites form peculiar spindle-shaped structures, such as in Dir (CHAUDHRY et al. 1974). Dunites form thick oval-shaped rock bodies in the Chilas area. MISCH (1949) described norites and hypersthene diorites as widely metamorphosed masses from the two flanks of the Nanga Parbat in a situation comparable to the Chilas Complex. The Kargil Igneous Complex in Ladakh, south of Astor, is a similar rock complex of noritic gabbros, hypersthene diorites and minor intrusives (RAI & PANDE 1983).

ASIF et al. (1985) and JAN et al. (1989) subdivided these rocks into two associations: a principal gabbro-norite association and a subordinate ultramafic association, composed of veins, sills and lensoid bodies (1 km^2 to 5 km^2) of ultramafic rocks, gabbro-norites, gabbros, anorthosites and mafic pegmatites, containing xenoliths of rocks of the principal gabbro-norite association. Such relations are also found in Swat as well as in Dir so that this division can be taken as of genetic origin. The prevalence of sedimentation structures in the ultramafic rocks could have been caused by turbulance in the magma chamber (JAN et al. 1989).

The Chilas and Jijal Complexes are considered root zones of the Kohistan Island Arc that were emplaced during Early Cretaceous and suffered granulite facies metamorphism at 750 ° to 850 °C and 5 to 6.5 kb (JAN 1980, BARD 1983). During uplift of the Arc, partial retrogression produced amphibolites and greenschists, as well as textural variations, especially along the southern, western and central parts.

2.253.4 Kohistan Batholith

The Kohistan Batholith is a part of a belt of the Trans-Himalayan plutonic complexes, situated north of the MMT/Indus-Tsangpo Suture (Fig. 2.3) and spread over 2,700 km length between eastern Afghanistan and Myanma (Burma). The mass equivalent to the Kohistan Batholith, located on the eastern side of the Nanga Parbat, is called the Ladakh Batholith (Fig. 2.24).

The Kohistan Batholith crops out over a distance of about 280 km between the eastern Afghanistan border and the Nanga Parbat. In the north, the Batholith intrudes into the belt of the Cretaceous to Early Tertiary Rakaposhi ophiolitic mélange; in the south it is separated from the Chilas Complex by amphibolites of the Northern Belt. It is a composite calc-alkaline intrusive that ranges from basic towards acid composition. In many places, such as in the Gilgit-Skardu areas, dolerites and lamprophyres

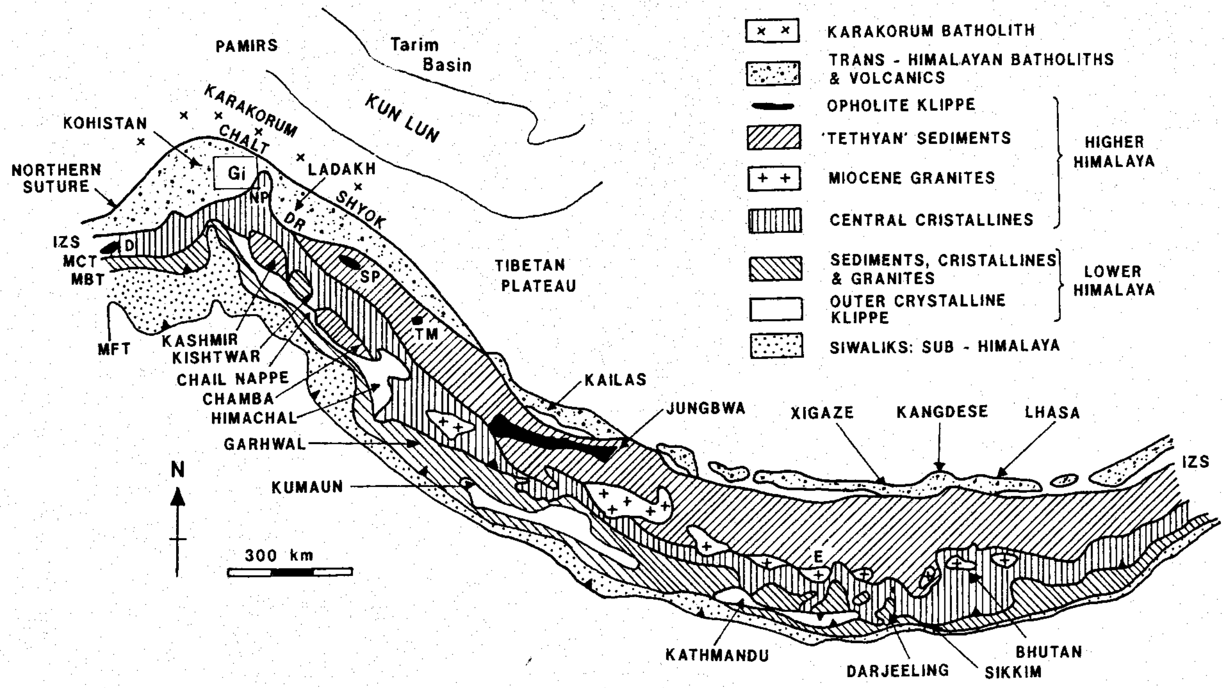


Fig. 2.24. Geological sketch map of the Himalaya showing the extent of the Trans-Himalayan Batholith. Position of sketch map northeast and east of MKT (Fig. 2.24 and Fig. 2.4) (modified after PETTERSON & WINDLEY 1986, Fig. 1). D: Dargai; DR: Dras; E: Everest; Gi: Gilgit area; IZS: Indus-Tsangpo Suture; MBT: Main Boundary Thrust; MCT: Main Central Thrust; MFT: Main Frontal Thrust; NP: Nanga Parbat; SP: Spontang; TM: Tso Morari.

are the youngest intrusions. More than 80 % of the Batholith is composed of diorites and quartz diorites, quartz monzonites and granites, whereas gabbros, pyroxenites and anorthosites constitute smaller volumes. Dykes of aplitic/pegmatitic granophyres and lamprophyres are rather common. The earlier phase of these intrusions is foliated while the younger intrusions are non-foliated. JAN & KEMPE (1973) and JAN (1979) described a section from upper Swat, N W F P, delineating diorites from noritic gabbros of the Chilas Complex.

South of Kalam (35° 04'N; 72° 28'E), diorites are separated by a screen of metasediments (JAN 1979). Hornblende, plagioclase, garnet and epidote are the major minerals of the diorites. In the Ushu-Gabral area of upper Swat, there are much younger granites that contain xenoliths of the diorite rocks (JAN 1979). These intrusives are plagioclase-bearing trondhjemites without potash feldspar. Nevertheless, some granites are normal two-feldspar rocks, containing biotite and locally hornblende.

In the Deosai-Ladakh region, east of the Nanga Parbat Massif, the Kohistan Batholith area extends towards the Indian territory. In the Kargil and Nubra-Shyok Valleys, the Batholith is intrusive into the Khardung Volcanics of Upper Cretaceous-Eocene age, which also occur as xenoliths in the Batholith (RAI & PANDE 1978, THAKUR 1981, RAI 1983). The Batholith is dominated by tonalites, followed by granodiorites and rare granites. Mafic rocks like hornblende gabbro and hornblendite are present in smaller volumes. Dolerites, aplites and pegmatites are the youngest dyke rocks that cut the Batholith.

On the basis of detailed studies, PETTERSON & WINDLEY (1985, 1986) gave a 2-fold division of the constituent plutons and minor intrusions of the Kohistan Batholith: (1) Early deformed plutons, composed of gabbro-diorites and tonalites containing hornblende and, in places, pyroxene relicts, with well developed foliation. The north Gilgit ridge gneiss and the Matum Das Pluton belong to this class. (2) Undeformed plutons that cut structures of the deformed plutons, ranging from hornblende gabbro to leucogranite. The Jutal-Matum Das Pluton is a representative example. On the basis of a study of 18 plutons of the Gilgit area, PETTERSON & WINDLEY (1986) showed that their initial Sr^{87}/Sr^{86} ratio ranges from 0.7039 to 0.7052, which is comparable to that of the Ladakh Batholith (HONNEGAR et al. 1982). Magmatism was active in the Kohistan Batholith and the Ladakh Batholith during the same period of time, from 105 mio. years to 15 mio. years ago.

2.253.5 Kalam Group

The Kalam Group (Fig. 3.6) is perched on the Kohistan Arc as several metasedimentary sequences that represent remnants of the crust above the Arc. The type section of the Kalam Group is exposed near Kalam, upper Swat, composed of quartzite, limestone and slate (MATSHUSHITA et al. 1965, TAHIRKHELI 1979). These rocks extend westward to Dir and exist as isolated outcrops towards the east, in the Kandia River (JAN 1970), near Sazin (DESIO 1974), south of Gilgit and Skardu (BARD et al. 1980). In the Kalam-Dir area, a progressive transition exists between the Northern Amphibolite Belt and the Kalam Group rocks.

At the type section, TAHIRKHELI (1979) subdivided the Kalam Group into three units: (1) The uppermost unit is the Shou Quartzite, about 600 m thick, which is an antiform structure that extends to Shringal Valley and beyond to Baraul Banda in Dir. This unit has an intrusive contact to the south against diorites, and a faulted contact to the north against the Baraul Banda Slate. (2) The middle unit is the Deshan Banda Limestone (Fig. 3.6), which is about 35 m thick, thin-bedded, fine-textured with sparse fossils. Fossil discoveries of *Rhabdophylia* sp. (KRAIG 1981) proved a Middle Jurassic to Cretaceous age. (3) The Karandoki Slate forms the lowest unit of the Kalam Group (Fig. 3.6). It is a sequence of mica schists, grading upward to phyllites, phyllitic slates and slates, about 120 m thick. These rocks are altered to hornfelse in contact with intrusive diorite rock bodies; they are also metamorphosed regionally to para-amphibolites which form at least a part of the northern amphibolites of Dir (TAHIRKHELI 1979). Notably, the slates are gradational into the Deshan Banda Limestone (Fig. 3.6).

The Kandia Schist, which is located in the Kandia River Valley between Tuti and Richa, before it joins the River Indus in Allai Kohistan, has been correlated with the Karandoki Slate by TAHIRKHELI (1982). These rocks crop out in the strike direction to the east of the Kalam Group Formations. The rocks are composed dominantly of slates, phyllitic schists, quartz-mica schists, garnet-mica schists and gneisses, with subordinate calcareous and arenaceous partings (JAN et al. 1970). On all sides, the Kandia Schist is surrounded by amphibolites. TAHIRKHELI (1982) correlated the Kandia Schist with the Karandoki Slate belonging to the basal part of the Kalam Group.

2.253.6 Dir Group

The Dir Group (Fig. 3.6) underlies a belt of volcanic-sedimentary rocks 1,000 m to 1,200 m thick that enters Pakistan from eastern Afghanistan in Bajaur, District Dir, and extends eastward to the Ushu Valley in upper Swat. It includes two mappable units, the Baraul Banda Slate and the Utror Volcanics (TAHIRKHELI 1979). The Baraul Banda Slate consists of thin-bedded, fine-textured slates that are isoclinally folded and have a faulted contact with the Shou Quartzite of the Kalam Group. Intercalations of thin-bedded limestone have yielded *Actinocyclina*, *Discocyclina* and *Nummulites atacicous*, indicating an Early Eocene age of the Slate. The Utror Volcanics, interbedded with the Baraul Banda Slate, consist of a sequence of andesites, dacites, rhyolites, tuffs and agglomerates as much as 4 km to 5 km thick. At least five major cycles of volcanism have been identified (TAHIRKHELI 1979). The age of the Utror Volcanics is regarded as Middle to Early Eocene, as this unit is interbedded with the Baraul Banda Slate that contains Early Eocene fossils. At many places, such as in the Baraul Valley, Dir, the Dir Group rocks are intruded by diorite rock bodies of post-Eocene age (ZEB 1979). In the Jandul Valley, Dir, feeder dykes and volcanic cones are exposed (Suraighat Hill).

2.253.7 Rakaposhi Volcanic Complex

The Rakaposhi Volcanic Complex (Fig. 3.6), which crops out north of the Kohistan Batholith, represents the thick oceanic crust that was formed in the Tethys between the converging Indo-Pakistan and Eurasian Plates. It extends continuously from eastern Afghanistan in the west to Baltistan and beyond in the east. Its outcrop belt is 3,000 m to 4,000 m wide in its widest section in the Karakorum Kohistan, Ishkuman and Yasin Valleys and in the Hunza area. It forms the Rakaposhi mountain (7,800 m) and thus displays the highest outcrop of ophiolites in the world. The Complex consists of volcanic flows, metasediments and syn- to post-tectonic intrusions; all these rock types are haphazardly intermingled. The volcanics consist of basalts, andesites, dacites and rhyolites, with conspicuous pillow-structures in the basalts (GANSSER 1980), that are well exposed in the Hunza River section south of Chalt (36° 16'N; 74° 18'E); the pillows are deformed along the shorter axes, showing their involvement in the MKT event in the north. Tuffaceous beds are traceable along the entire length and consist of biotite schist, hornblende schist, schistose amphibolites, hornblende-epidote schists and actinolite schists (TAHIRKHELI 1982). The metasediments include slates, phyllites, phyllitic schists, quartzites, crystalline limestones and marble. These rocks are mainly exposed near Ashret, south of Drosh, Chitral, north of Shigar, Baltistan, and between Gakuch and Gupis, Ghizar Valley (TAHIRKHELI 1982).

Ultramafic to acid intrusives in the Rakaposhi Complex include gabbros, diorites, hornblendites and pyroxenites, granodiorites, granites and aplite-pegmatites. These have thermally metamorphosed the metasediment inclusions within these intrusives. The entire rock suite is also metamorphosed, with the intensity increasing towards the Nanga Parbat Massif.

Globotruncana sp. was found in the Tissar section of the Complex, north of Shigar (35° 25'N; 75° 43'E), and *Thaninasteria matshushitai* in outcrops at Shamran in the

Ghizar Valley; thus, the age of the Rakaposhi Volcanic Complex is believed to be Early Cretaceous (TAHIRKHELI 1982, MATSHUSHITA et al. 1956).

2.253.8 Yasin Group

The Yasin Group (Fig. 3.6; "Upper Detrital Series" of BARD et al. 1980) constitutes the youngest remnants of the Tethys, located on the northern edge of the Kohistan Arc as tectonic slices, near Yasin, near Drosh, Chitral District, and near Katzara, Baltistan. Many more but small outcrops are seen at many locations along the northern periphery of the Kohistan Arc. The southern contact of the Yasin Group rocks is with the Rakaposhi Volcanic Complex, where these rocks are locally interbedded with volcanic flows. Pre- to post-tectonic intrusions of acid to basic igneous bodies are common in the Yasin Group (TAHIRKHELI 1982).

At Drosh, Chitral District, the westward extension of the Yasin Group consists of slates, phyllites, phyllitic schists, crystalline limestone and marble. The base of the Group is in sheared contact with the Rakaposhi Complex (HAYDEN 1915, DESIO 1963). The calcareous strata in this Group have yielded fossils of hippurites, corals and *Orbitolina* sp. of Cretaceous age.

Outcrops of the Yasin Group are also exposed in the Shigar Valley, north of Skardu, in the Deosai Plateau at Burji-La and in the Burzil Pass area (BARD et al. 1980).

In Baltistan, the rocks of the Yasin Group have been named Katzara Formation (Fig. 3.6; DESIO 1963) composed of shales, siltstones, slates and quartz-mica phyllites, with intercalations of quartzitic sandstones, considered Cretaceous-Eocene in age.

2.253.9 Main Karakorum Thrust Zone

The Main Karakorum Thrust (MKT) Zone marks the contact between the Eurasian Plate (continent) in the north and the Indo-Pakistan Plate (continent) in the south. The Zone is occupied by rocks of the Chalt ophiolitic mélange composed of andesite, basalt, serpentinite, ophi-calcite and rare peridotite. In the Ishkuman Valley, the mélange contains a breccia unit of rock fragments derived both from the Kohistan Arc and the Eurasian Plate (DESIO 1963, TAHIRKHELI 1979, 1982, GANSSER 1980, COWARD et al. 1982). The mélange zone is exposed at many locations along the length of the MKT Zone which extends eastwards to Khapalu (35° 09'N; 76° 19'E) and beyond into the Shyok Valley, India (GANSSER 1980, TAHIRKHELI 1982).

In the Ishkuman Valley, a mélange zone is about 1.5 km wide composed of large blocks of quartzite, minor greenschist and limestone in a matrix of carbonaceous slate (COWARD et al. 1986). Near Khapalu, 50 km east of Skardu, the mélange is ophiolitic, and consists of serpentinite, pyroxenite, greenschist, amphibolite, gabbro, phyllite, gneiss, marble, volcanics, chert, greywacke and mica schists (ZANETTIN 1964, BROOKFIELD 1981). In the Shigar-Shyok Valleys, the mélange consists of three belts or parts (FRANK et al. 1977, RAI 1983) of different lithologies.

The westernmost exposures in Pakistan, the Chitral section, shows an up to 3 km wide MKT Zone in the lower Shishi Valley, 2 km wide in the Harchin area, but is reduced to only a 150 m wide fault zone in Naz Bar, before it thickens again to 4 km in the Hunza area (PUDSEY et al. 1985). No blueschist metamorphism has been discovered along the MKT Zone.

2.253.10 Molasse deposits

Molasse deposits accumulated in the Deosai-Ladakh domain of the Kohistan Island Arc (Kailas Molasse, Ladakh Molasse), at the southern side of the Ladakh Batholith. Molasse deposits (Jalipur Molasse, GANSSER 1980) are exposed along the Indus Valley, northwest of the eastern flank of the Nanga Parbat Massif. The molasse consists of badly sorted conglomerates and sands of nearby origin but with porphyrites, porphyries and trachytes that are rather foreign to the area. The formation resembles the Upper Siwaliks of Pliocene age. West of Gupis, District Ghizar, similar molasse deposits are also found in the valley of the River Ghizar (Ghizar Molasse, TAHIRKHELI 1982).

2.254 The Karakorum Block

Going north of Chalt (32° 56'N; 72° 51'E) along the Karakorum Highway and crossing the Main Karakorum Thrust (MKT) Zone, one steps on the southern edge of the Karakorum Block, to which the Kohistan Island Arc was accreted during Late Cretaceous time as a result of the northward drift of the Indo-Pakistan Plate (Fig. 2.4). The Karakorum Block extends from the Pakistan-Afghanistan border in the west to western Tibet in the east; its northwestern limit is marked by the Chitral Fault and the northeastern boundary is defined by the Karakorum Fault. The upper Hunza Fault is taken as its northern limit (DESIO 1979) or the Rushan-Pshart Fault of central Pamir (SHVOLMAN 1981).

The Karakorum Range is over 600 km long with an average width of 150 km, forming a cresent-shaped belt convex northward. Its rocks were once a part of the Gondwanaland, but during the Triassic they rifted and started drifting northward in an counter-clockwise manner. This resulted in the closure of the Palaeo-Tethys in the north and opening of the Neo-Tethys in the south (Fig. 6.6). Continued northward drift resulted ultimately in the accretion of the Karakorum Block to the southern edge of the Eurasian Plate (SENGÖR 1984).

The Karakorum Highway exposes a transverse section of the Karakorum Range. Going north to Khunjerab Pass on the Pakistan-China border, three distinct lithologic belts are crossed: The **Karakorum Metamorphic Belt**, the **Karakorum Axial Batholith** and the **Karakorum Sedimentary Belt**; the belts are essentially oriented conformable to the arcuate structure of the Karakorum Block. Notably, grades of metamorphism, sedimentary facies, tectonic styles and eruptive activities exhibit variations along the length of the orogen. The Baltoro-K2 zone represents the eastern-most Karakorum in Pakistan, with K2 as the second highest peak (8,611 m) in the world. The geologic-tectonic model for this zone laid the basis for the rest of the orogen (DESIO 1963, 1964, 1980).

The **Karakorum Metamorphic Belt** is located between the Karakorum Axial Batholith in the north and the MKT Zone (= Shyok Suture zone) in the south

(Fig. 2.4). The Dumordo Formation (or Group; Fig. 3.2) is the oldest Formation exposed in a northwest-southeast trending belt that extends beyond the Hispar Valley into the upper Hunza area (see Chapter 3.21). The Group is many thousands of metres thick and displays considerable variations in lithology. Proposed ages of the Dumordo Formation range from Permian (see Chapter 3.24), Early Paleozoic (DESIO 1979) to Precambrian (WADIA 1932). Structurally underlying the Dumordo Group in the south and north of Shigar, in the Braldu Valley and extending southeast, the Dassu Gneiss (DESIO 1964) is exposed, grading upward into garnetiferous schist; its age is unknown. Further southeast, the Daltumbore Formation (Fig. 3.2) of Devonian/Carboniferous/Permian age is exposed, consisting of mica schist more than 1,200 m thick. The Daltumbore mica schist, of turbidite origin, grades imperceptibly into the Skoro Lumba Slate (Lugma slates in Chapter 3.24), which is 800 m to more than 2,500 m thick and contains thick limestone layers. Northward, the Nang Brok Quartzite, more than 1,000 m thick, of Late Cretaceous to Eocene age, is present, with intercalations of paraschists that compare with the Daltumbore mica-schist (DESIO 1979). SEARLE et al. (1986) proposed that the protoliths for these metasediments evolved out of even proportions of impure muddy limestones and shales with minor volcanics, possibly representing a collapsed passive-type continental margin. Adjoining the Shyok Fault (Fig. 2.3), the metasediments underwent retrogressive alteration of kyanite, staurolite, garnet to muscovite and chlorite-bearing assemblages, such as west of Mango Gusar.

Between Basha, in the Hoh Lumba and Masherbrum Valleys, the Ganchan Formation (DESIO 1964) of unknown age is exposed as a northwest-trending belt, composed of biotite-amphibole, garnet, and epidote-bearing gneisses along with garnetiferous amphibolites and thick beds of marble and crystalline dolomite. The Formation disappears in the Chogo Lungma Range, beyond which the Chalt Ophiolitic Melange appears. Eastward, rocks of the Ganchan Formation are interposed between the Baltoro Pluton and the Dumordo Group north of Bakhor (DESIO 1964, 1985); the metamorphic grades decrease normally upward.

North of the Dumordo and the Ganchan Formations, the **Baltoro Plutonic Complex** is exposed in a belt 20 km wide and about 100 km long, between Snow Lake in the northwest and Masherbrum and Chogolisa in the southeast. As a part of the Karakorum Axial Batholith, the complex covers mainly the Baltoro Basin and the Panmah glacier areas. The Baltoro Pluton is a homogeneous rock body, composed mainly of biotite granite and leucogranite, both cut by aplite and pegmatite veins and dykes. The northern contact of the pluton has a well-developed thermal aureole containing andalusite and sillimanite-bearing hornfelses, whereas the southern contact is against foliated gneisses. Notably, there are no mafic dykes, and tourmaline is absent in contrast to the post-tectonic Himalayan granites. The initial $^{87}Sr/^{86}Sr$ ratios range between 0.7072 and 0.7128, indicating a crustal derivation, with 21 ± 0.5 mio. years as the age of crystallization (REX et al. 1988).

South of the Baltoro Plutonic Complex and along the Hushe Valley, the Hushe Complex appears as the oldest component of the Karakorum Axial Batholith, with meta-aluminous and per-aluminous parts as distinct intrusions. Hornblende from the foliated Hushe Gneiss yielded a Triassic age (203 – 208 ± 1 mio. years, $^{39}Ar/^{40}Ar$) with initial $^{87}Sr/^{86}Sr$ ratios of 0.705 to 0.713, which indicates that older crustal material was incorporated during intrusion (REX et al. 1988).

Occupying most of the northeastern part of the Biafo Valley, and the northern part of the Hispar Valley, the Biafo Pluton is yet another component of the Karakorum Axial Batholith. It is a medium-grained rock, with two-mica granitic composition in the Biafo area, and granodioritic composition in the Hispar area. DESIO et al. (1964) assigned a Miocene age to the Biafo Pluton.

North of the Baltoro Plutonic Complex, the Sarpo Laggo-K2 complex appears as a highly deformed belt of low- to medium-grade metamorphics, extending southeastward and composed of ortho- and para-gneisses, marbles and pegmatites. At the confluence of Sarpo Laggo and Skamri streams, the rocks are only slightly metamorphosed; here, the sandstones and cherty limestones contain Fusilinids (*Monodiexodina*), showing their Permian age (GAETANI et al. 1990).

Northward, the Main Karakorum Thrust Zone (see Chapter 2.253.9) is exposed, with rocks mainly of brittle deformation, such as syn-metamorphic mylonites, meta-conglomerates and foliated carbonaceous slates. A gravity profile across the Sarpo Valley showed a discontinuity that marks the edge of the Karakorum micro-plate (GAETANI et al. 1990).

The 15 km- to 20 km-wide Shaksgam Valley, northeast of the Karakorum Fault zone, is occupied by the Shaksgam Sedimentary Belt, about 3 km thick, with a Permian to Jurassic fauna (DESIO 1980, GAETANI et al. 1990). Other sedimentary sequences are present in the south and in the southeast, including the Late Carboniferous to Early Permian Singhie Shale, and the Late Cretaceous Urduk Conglomerate (DESIO 1980). In the northeast of the Shaksgam Formation, however, crystalline complexes are prominent (Aghil Dara Granodiorite, Kun Lun Crystalline Complex) belonging to the Hercynian realm.

The Hunza Valley zone has been intensively investigated. The Karakorum metamorphic belt is here again dominated by the rocks of the Dumordo Group, that extends northwestwards without break from the Baltoro-K2 zone with essentially similar lithologies, but showing inverted metamorphic grades (BROUGHTON et al. 1985). Some of the marble layers in the Dumordo Group north of Baltit (Hunza) carry ruby corundum that has been mined for many years (OKRUSCH et al. 1976; see Chapter 9.4).

Between Hini and Saret, the Hunza Valley exposes a complete section of the Karakorum Axial Batholith as a medium-grained granodiorite, younger two-mica granite and quartzofeldspathic veins and dykes. A crustal parentage is hinted by the high initial $^{87}Sr/^{86}Sr$ ratio of 0.710, and a complex evolutionary history by the wide range of absolute ages from 5 mio. years to 95 mio. years (DESIO et al. 1964, LEFORT et al. 1983, CASNEDI et al. 1978).

North of the Karakorum Axial Batholith is a thick series of Paleozoic and Mesozoic sediments that has not suffered recognizable metamorphism, in contrast to the formations north of the Baltoro Plutonic Complex. Following the pioneer works of DESIO (1963, 1964, 1971) and DESIO & MARTINA (1972), the series has been divided into three litho-tectonic units or belts by GAETANI et al. (1990).

(1) The Pasu Slate (Fig. 3.2) and the Misghar Slate (Fig. 3.2) are the low-grade metasedimentary rocks of the upper Hunza area, occurring immediately north of the Karakorum Axial Batholith, and in the northern border zone of the country. The Pasu Slate (SCHNEIDER 1957) consists of black to dark-grey, dominantly arenaceous rocks

with minor black limestone and yellow quartzite; DESIO & MARTINA (1972) proposed a Carboniferous age. The Misghar Slate (DESIO 1963) is a greenish and black schistose rock, about 5,000 m thick, with intrusions of acidic and syenitic bodies; the Giraf Syenite with big, pink feldspar phenocrysts, has been dated at 53 mio. years (DESIO 1979). Similar rocks extend towards Wakhan, where they yielded Eearly Triassic conodonts (BUCHROITHNER 1980), representing continental-rise type deposits.

(2) The oldest sedimentary rocks of the upper Hunza area are represented by the Gircha Formation (Fig. 3.2; DESIO 1963) consisting of alternating pelites and sandstones, which are fossiliferous in places and yield *brachiopoda* of Early Permian age. These rocks were deposited in a rapidly-subsiding rift trough with sediment dispersal toward northwest (GAETANI et al. 1990). The succeeding Panjshah Formation of Artinskian age consists of arenites and siltstones with interbedded fossiliferous carbonaceous layers, indicating a transgression during the Permian (GAETANI et al. 1990).

(3) The overlying Kundil Formation is composed of a shaly-marly succession including a few volcanic tuff horizons, which represents deep water sedimentation from Permian to the stage of deposition of the Borom Formation of Triassic age. The Borom Formation consists of black platy limestones containing chert and reworked carbonate sediments, deposited under shallow water conditions. The succeeding Aghil Formation (Gujhal dolomite of DESIO 1963) is a platform complex of massive dolomites and limestones, many hundred metres thick, extending up to the Liassic period of time (beds rich in *Lithiotis*).

GAETANI et al. (1990) showed that the Middle Liassic Yashkuk Formation, well developed in the Chapursan Valley and thinning eastward, signifies a tectonic event because of the recycled orogen provenance of this terrigenous sediment. The Middle Jurassic Reshit Formation represents continued shallow marine deposition of fossiliferous mudstones and bio-intraclastic calcarenites. These environments continued to the Late Jurassic time; no marine sediment of younger age has been located yet in this area (GAETANI et al. 1990).

The Permian to Jurassic succession of the upper Hunza area was truncated by an unconformity due to overlying Tupop Formation (GAETANI et al. 1990), composed of cobble conglomerates, interbedded sandstone and unfossiliferous nodular limestone, with a southward transport direction of the clastics. GAETANI et al. (1990) assigned a Middle Cretaceous age and suggested that the Tupop Formation indicates a tectonic episode in the Karakorum microplate earlier than the Himalayan orogeny.

The Karambar and Ishkuman Valleys, west of the upper Hunza Valley, show a westward extension of various Formations with lesser degrees of metamorphism. The eastern part of the Gamugal Pluton represents the Karakorum Axial Batholith whereas the Hindu Raj Granodiorite, constituting the core of the Hindu Raj Range in the north, compares with the Giraf Syenite of the Chapursan Valley in the upper Hunza area. The limestones and sandstones of a thick sedimentary sequence, north of the Hindu Raj Pluton, yielded Permian to Liassic fauna, whereas Cretaceous *Orbitolina* are found in conglomeratic sequences (CASNEDI 1981), comparable to the Tupop Formation of the upper Hunza area.

In the Yasin Valley, west of the Karambar-Ishkuman Valleys, the Upper Paleozoic sequence is developed on both sides of the Gamugal Batholith. This sequence consists of shales and phyllitic schists about 2,000 m thick, including a zone of acidic sills and dykes adjoining the northern flank of the Batholith. It is succeeded by about 1,000 m of dolomitic limestones containing recemented breccias, as well as minor amounts of grey siltstones and shales, considered to be of Carboniferous age (CASNEDI 1976). An overlying cherty limestone, about 10 m thick, is succeeded by a sequence of clastic limestones, shales and sandstones of Early Permian age (HAYDEN 1916). North of the Rawat Fault, which truncates the Permian sequence, a metasedimentary assemblage is exposed that consists of slates, phyllites, calc-schists dykes and sills. North of the Hindu Raj Granodiorite, garnet grade schists are found that extend to the Pakistan-Afghanistan border. According to CASNEDI (1976), the granodiorite belongs to the Karakorum Axial Batholith but correlates with the Giraf Syenite of the upper Hunza area, dated at 53 mio. years (DESIO 1979).

In Chitral, most of the area is underlain by Paleozoic and Mesozoic sedimentary rocks and elongated intrusives of the Karakorum Axial Batholith. The Karakorum microplate narrows to a width of 20 km to 40 km, limited by the Reshun Fault in the north and the MKT Zone in the south. The Permo-Carboniferous Darkot Group of IVANAC et al. (1956), equivalent to the Dumordo Group of DESIO et al. (1972), occupies a northeast-trending belt intruded by granodiorite plutons. The sedimentary rocks consist of slates and quartzites, with localized sandstones and conglomerates (PUDSEY et al. 1985). The Yarkhun Limestone conformably overlies the slates. In strike direction, the Gahiret Limestone (Fig. 3.6) as much as 3 km thick is exposed southwest of the Istorini Ridge. Near Jingeret, diorite gneiss and metasediments follow above the Gahiret Limestone. In the west, an exposure of the Koghozi Greenschist as much as 4 km wide has been observed (DESIO 1975), believed to represent altered tuffs. PUDSEY et al. (1985) regard the Koghozi Greenschist as of Jurassic age and the Gahiret Limestone as of Cretaceous age. The Chitral Slate (Fig. 3.6) represents the oldest (Precambrian) Formation of the area, composed of slates, sandstones and greywackes (TAHIRKHELI 1980); an age range from Cretaceous to Permian has been suggested by PUDSEY et al. (1985). The Chitral Slate is overlain by the massive to banded Krinj Limestone (Fig. 3.6), which is as much as 2.5 km thick. It becomes dolomitic in the west and cherty in the east; near Krinj (stibnite mines; see Chapter 8.7), the limestone contains *Orbitolina* and *rudists* of Cretaceous age (DESIO 1959, 1975).

Above the Chitral Slate and below the Reshun Fault, a varied group of rocks is defined as the Reshun Formation (Fig. 3.6; CALKINS et al. 1981) including polymict conglomerates, shales and limestones with variations along strike direction. About 5 km east of Buni, a bed of limestone breccia and limestone pebble-conglomerate overlies the polymict conglomerate. Aptian-Albian fossils have been reported from shale and limestone of the Reshun Formation (TALENT et al. 1982); some of the conglomerates may be even younger.

The metasediments of the Chitral area are intruded by plutons belonging to the western extension of the Karakorum Axial Batholith; most prominent are the Kesu-Buni Zom Pluton, the Dobargar Pluton and the Zagar-Umalsit Pluton. These intrusives are mostly dioritic to granodioritic, but include younger, almost undeformed, granites and minor acidic rock bodies. In the Yasin Valley, the Umalsit Pluton yielded 56 mio. years and 40 mio. years K/Ar isochron ages (CASNEDI et al. 1978).

During the **evolution of the Karakorum Block**, the Permian and Triassic have been important periods. Marine transgressions late in the Early Permian occupied the north-dipping margin of Gondwanaland. The deposition of sandstones with continental provenance indicates subsiding rift-troughs. By Middle Permian, the sedimentation rate dropped because of the deepening marine environment, but by Late Triassic, the sea became shallower and the sedimentation rate was increased, leading to the development of platform conditions that persisted up to Middle Liassic time. These events are believed to be linked to the incipient Neotethys opening in the south. During the Middle Liassic, the Karakorum Block suffered an orogenic event without itself being much involved in the deformation; the sediments at this stage show detrital components of a recycled-orogen provenance. Marine conditions continued until Late Jurassic, with intense faulting during Middle Jurassic; no younger marine deposit has been discovered so far. During Cretaceous time, however, a major orogenic event took place in the region, recorded by thick conglomerate beds truncating the Permian to Jurassic succession. This event was probably linked to the violent accretion of the Kohistan-Ladakh Arc terrane with the Karakorum Block at ca. 100 to 90 mio. years ago (COWARD et al. 1986, GAETANI et al. 1990). With this also ended the pre-collisional stage of igneous intrusions (Hushe Pluton, 203 - 208 mio. years; K2 Gneiss, 115 mio. years; Hunza Granodiorite, 95 mio. years). The range of initial $^{87}Sr/^{86}Sr$ ratios of these plutons shows that they derived from subduction-related crustal material but with contributions from older material and/or upper mantle rocks.

During the Late Cretaceous, ca. 50 mio. years ago, another major event occurred, involving the collision of the Indo-Pakistan Plate with the Kohistan-Ladakh region that had already accreted to the Karakorum Block (SEARLE et al. 1987). This event was responsible for the post-collisional metamorphism and deformation on both plates across the Main Mantle Thrust. The rock melts, produced by crustal subduction, gave rise to the post-collisional intrusions of granites (Hunza Valley plutons, 8–25 mio. years; Baltoro Pluton, 21 mio. years) but the much younger ages may indicate resetting of the clock, because of post-intrusive thermal events (LEFORT et al. 1983). Contact metamorphism and migmatisation are characteristic phenomena of this period.

Intense folding and thrusting has been imposed by the Cenozoic Himalayan orogeny, also giving rise to low-grade metamorphism and metamorphic retrogression. During the Quaternary period, the Karakorum Block has been deformed by strike-slip faulting such as related to the Karakorum Fault, which shows approximately 150 km of right-lateral offset (MOLNAR & TAPPONIER 1975).

2.255 The Hindu Kush elements

The territory from north of the Reshun Fault to the Pakistan-Afghanistan border constitutes a part of the northeasterly extension of the Hindu Kush Range. It merges with the southwestern Pamir.

Immediately north of the Reshun Fault, a sequence of carbonate rocks as much as 5 km thick, of Devonian age, is exposed (HAYDEN 1915, IVANAC et al. 1956). This sequence is composed of two units, the Charun Quartzite and the Shogram Formation (Fig. 3.2). The Charun Quartzite is a white, medium-grained rock as much as 100 m thick, and contains Devonian brachiopods (STAUFFER 1975, TALENT et al. 1982). Kuragh is an important fossil locality, about 9 km east of Reshun, from where Early and Late

Devonian fossils have been described by TALENT et al. (1982). The Shogram Formation is about 800 m thick, consisting of massive crinoidal dolomite overlain by bedded dolomite that includes fossiliferous limestones and shales, with quartzite at the top (DESIO 1966). A reef complex was discovered by STAUFFER (1975) near Kuragh with an assemblage of stromatoporoids, corals and brachiopoda. Thus, a rather shallow marine environment was envisaged for these Devonian rocks (KLOOTWIJK & CONAGHAN 1979).

The northern edge of the Shogram Formation, north of the Reshun Fault Zone, is mostly faulted against a thick formation of clastic sediments; in places the relationship may be conformable such as east of Reshun. This is the so-called Lun Shale (the predominant constituent is slate in the Turikho Valley, north of Buni). West of Buni, however, dark-grey to black, rather soft shales are exposed, which weather rapidly. Toward the southwest, green phyllites are exposed, along with thin schistose conglomerate, at the same stratigraphic level. The clasts in the conglomerate are mostly below 2 m across and consist of quartzites, tuffs and slates.

In the Turikho Valley, the Lun Shale contains numerous quartzite layers as much as tens of metres thick. These quartzites show many sedimentary structures and burrows of *Planolites*. Intercalations of grey limestone contain abundant fossils of bryozoa, corals, brachiopods, crinoids and fusulina of Permian age, the associated slates and quartzites yielded no fossils (PUDSEY et al. 1985). TALENT et al. (1982) described Permian fusulina limestone from near Rosh Gol, along with dolomitic breccia, micritic limestone, thin shales and sandstones; a Late Permian age was suggested for the Lun Shale.

In the Lutkho Valley, about 4 km west of the Reshun Fault, grey slates replace green slates that show increasing metamorphism westwards. In the north, the soft shales contain Mesozoic (probably Jurassic) belemnites (TIPPER in PASCOE 1923). Southeast of the Yarkhun River, and from Reshun to Karagh, a major limestone unit, called Zait Limestone (Fig. 3.6), is exposed, believed to be a fault slice that brought up the Permian rocks within the Devonian sequence (DESIO 1966).

In the northwest part of the Lutkho Valley particularly, elongate granitic plutons intruded the metasediments. Hot springs (see Chapter 7.5), the Tirich Mir and Kafirstan intrusions are notable. Their composition ranges from biotite granodiorite to two-mica granite. Garnet and tourmaline are common accessories. Foliated facies show a distinct augen-gneiss structure (FORCELLA 1978). The Rb-Sr absolute age for a specimen of the Tirich Mir Granite is 115 ± 4 mio. years (DESIO et al. 1964). A similar age can be taken for the other plutons except for their younger aplitic-pegmatitic facies. The plutons are for the most part conformable to the metasediments, the Tirich Mir Granite shows complete structural unanimity, with the granitic veins showing pinch and swell structures within the metasediments (PUDSEY et al. 1985).

3. Sedimentary sequence

(Ali H. Kazmi)

The stratigraphic sequence in Pakistan ranges from Precambrian to Recent. Precambrian metasediments cover the Archaean gneissic complex of the Indian Craton and form the upper part of the basement complex. A few inliers of these metasediments are exposed in the Indus Basin (see Chapter 5.21). Tectonised Precambrian and Paleozoic metasediments are also exposed in anticlinal cores and in thrust sheets in the Himalayas, the Karakorum and the Hindukush Ranges (see Chapter 2.25). The Mesozoic and Palaeogene sedimentary rocks form a thick pile of pericratonic shelf deposits in the West Pakistan Foldbelt region (see Chapters 2.23, 5.23) along the margins of the Indo-Pakistan Plate (Fig. 3.1). Tectonically mixed sequences of Cretaceous and Palaeogene sedimentary and volcanogenic rocks are found in the Chagai-Raskoh Block (see Chapters 2.21, 7.1). The Cenozoic sedimentary sequence attains its maximum thickness in the foredeeps (see Chapter 2.24) and the adjacent areas of the West Pakistan Foldbelt (see Chapter 2.23), and in the Makran Flysch Zone (see Chapter 2.22). Quaternary alluvial and aeolian unconsolidated sediments cover vast areas in the intermountain basins and the Indus Plain. Quaternary glacial and fluvioglacial deposits are confined to the valleys and gorges of the Himalayas and Trans-Himalayan ranges.

There is an extensive and impressive list of authors who have contributed to the knowledge of the stratigraphy of Pakistan since the middle of the last century. As may be expected there has been a proliferation of stratigraphic nomenclature, and different authors have coined different names for the same suite of rocks. To systematise stratigraphic nomenclature in accordance with the National Stratigraphic Code of Pakistan (Rahman 1962), the National Stratigraphic Committee has reviewed and approved a set of standard lithostratigraphic names for the stratigraphic sequence in different parts of the country (Cheema et al. 1977; Fatmi 1973, 1977; Shah 1977, 1987). Accordingly, a brief description of the sedimentary sequence in Pakistan is given in the following pages. The results of more recent stratigraphic investigations have been, as far as possible, integrated in the existing scheme. Some lithostratigraphic names have been newly proposed, and the reasons are discussed.

3.1 Precambrian sedimentary rocks

Precambrian sedimentary rocks crop out in the Punjab part of the Indus Plain, in the Salt Range and Attock-Cherat Ranges and in the Himalayas. On a regional scale the

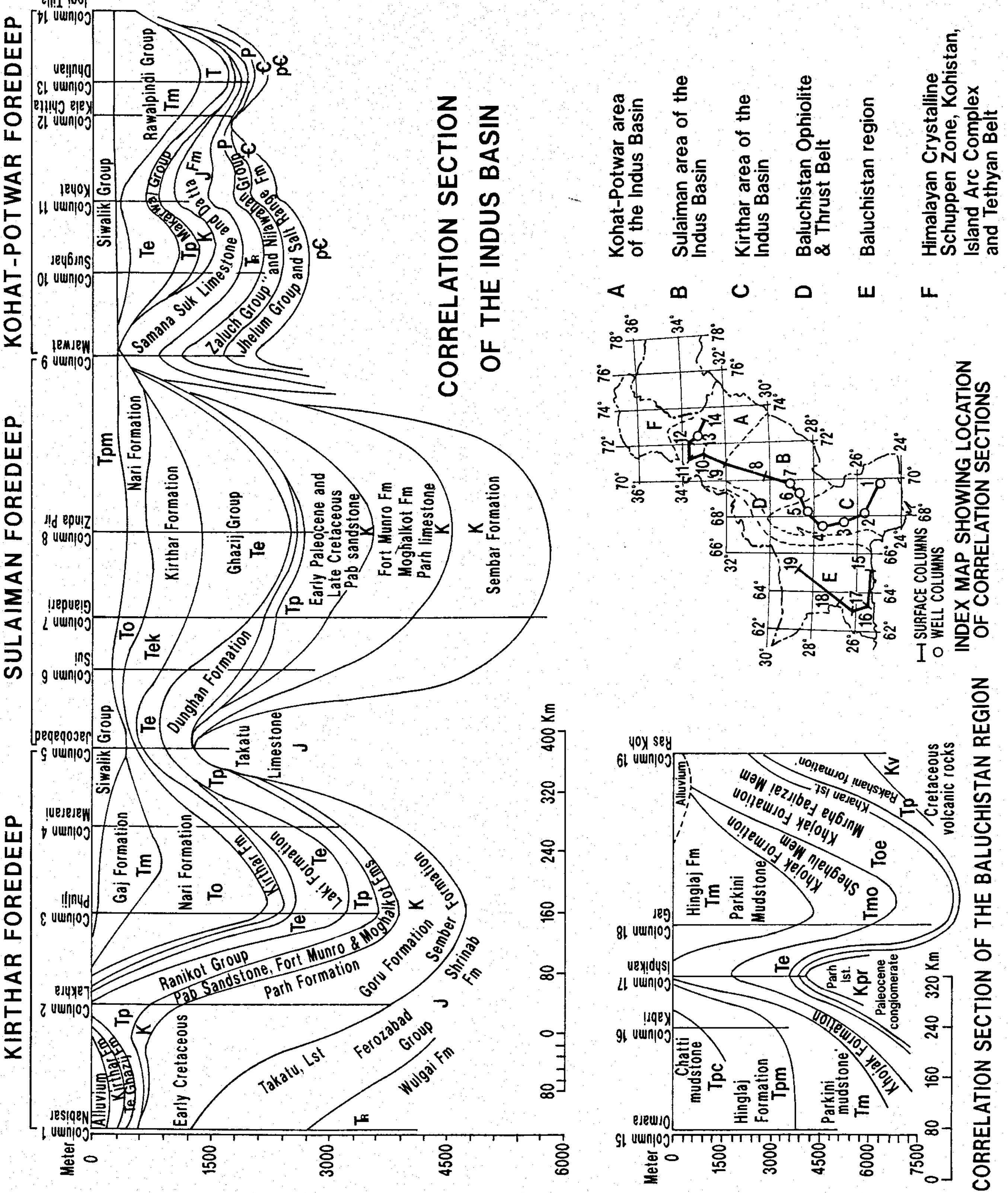


Fig. 3.1. Correlation of the sedimentary sequences of the Indus Basin and the Baluchistan region. P = Precambrian, C = Cambrian, P = Permian, T = Triassic, J = Jurassic, K = Cretaceous, Tp = Paleocene, Te = Eocene, To = Oligocene, Toe = Oligocene and Eocene, Tmo = Miocene and Oligocene, Tm = Miocene, Tpm = Pliocene and Miocene, Tpc = Pliocene Chatti Mudstone (modified after Bakr et al. 1964).

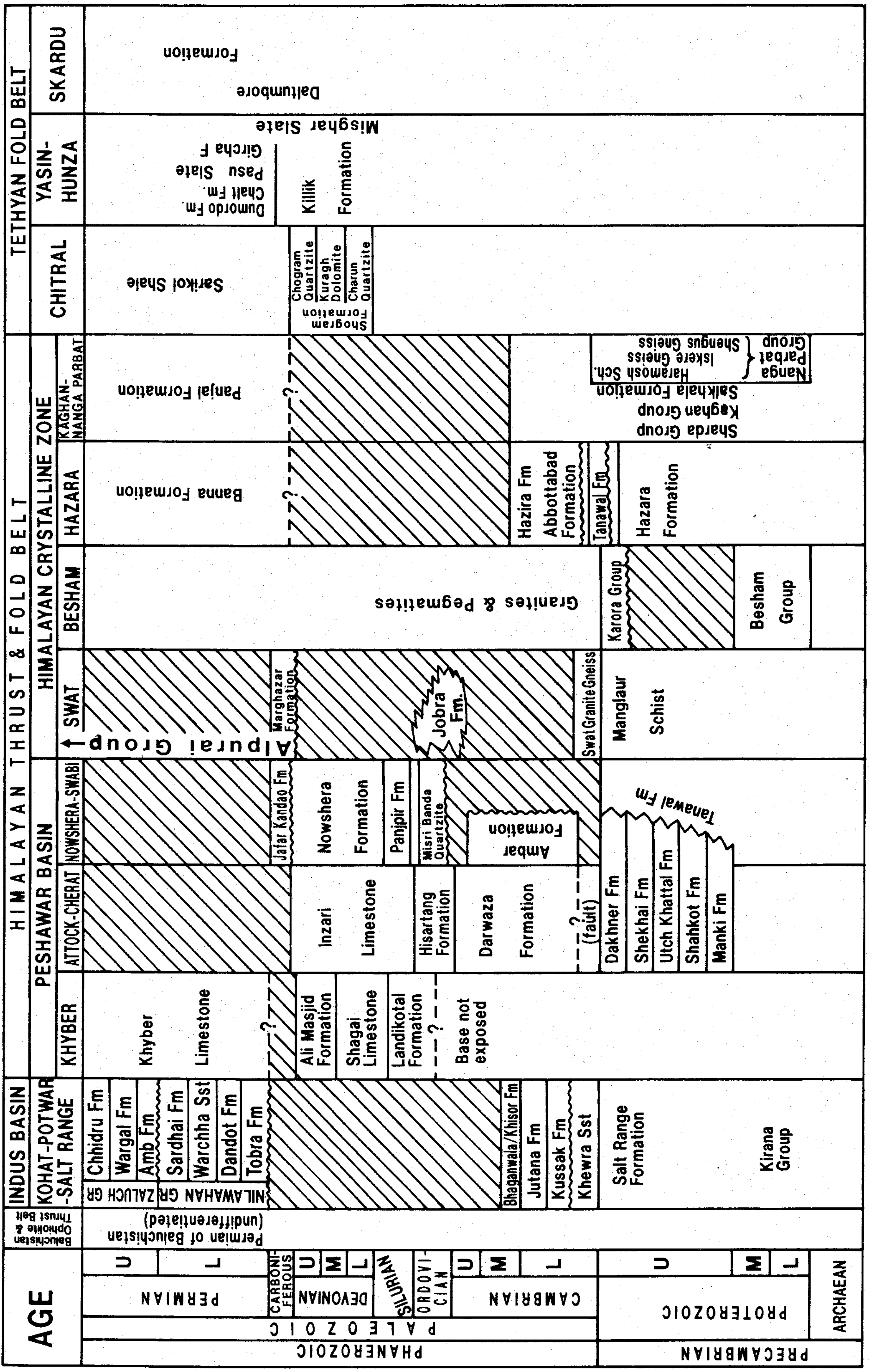


Fig. 3.2. Correlation of the Precambrian and Paleozoic sequences.

correlation of the Precambrian stratigraphic sequence is shown in Fig. 3.2. These rocks have been extensively metamorphosed and they are mostly in nappes or disjointed thrust slices or fault blocks. This feature has made their correlation difficult and has given rise to a large number of formation names by different authors.

The metamorphosed Precambrian sediments of the Indian Shield in the Indus Basin are discussed in Chapter 5.21. KAZMI (1964) introduced the name "**Kirana Group**" for the series of rocks, which has been dated as 870 ± 40 mio. years (Rb/Sr) by DAVIES & CRAWFORD (1971). The metasediments of the Kirana Group consist of phyllites, slates, quartzites and subordinate conglomerates which have been subdivided into five formations: the **Hachi, Taguwali, Asianwala, Hadda**, and **Sharaban** formations (ALAM 1983). The total thickness of the sequence is quoted as more than 2,330 m. Metamorphic basement rocks have also been encountered by several wells drilled to the north and south of the Sargodha High (Fig. 5.3).

Along the northwestern flank of the Indian Shield, the basement rocks are overlain by the non-metamorphic sediments of the **Salt Range Formation** (ASRARULLAH 1967), formerly decribed as "Saline Series" by GEE (1945). Type locality is the Khewra gorge in

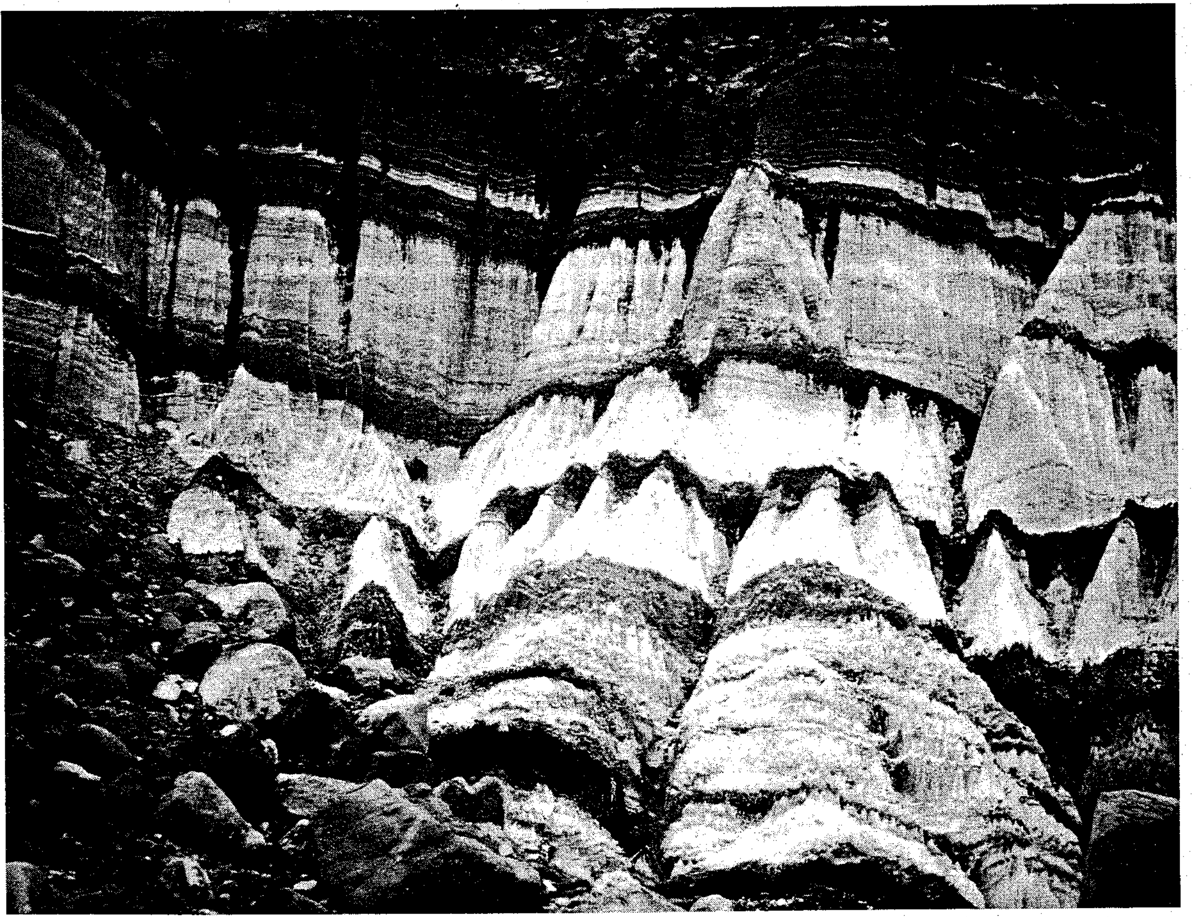


Fig. 3.3. White rock salt with brownish shale beds, laminated near the contact with the overlying Khewra Trap. Upper part of the Salt Range Formation (Upper Proterozoic). Vertical exposure about 10 m. Nila Wahan, Salt Range (Photo: H. PORTH).

the eastern Salt Range. The Salt Range Formation is widely distributed in the Salt Range, between Jogi Tilla (32° 51'N; 73° 27'E) in the east and Kalabagh (32° 58'N; 71° 34'E) in the northwest. It was also encountered by wells in the Kohat-Potwar foredeep and in the southern Punjab area, along the shallow eastern flank of the Sulaiman foredeep.

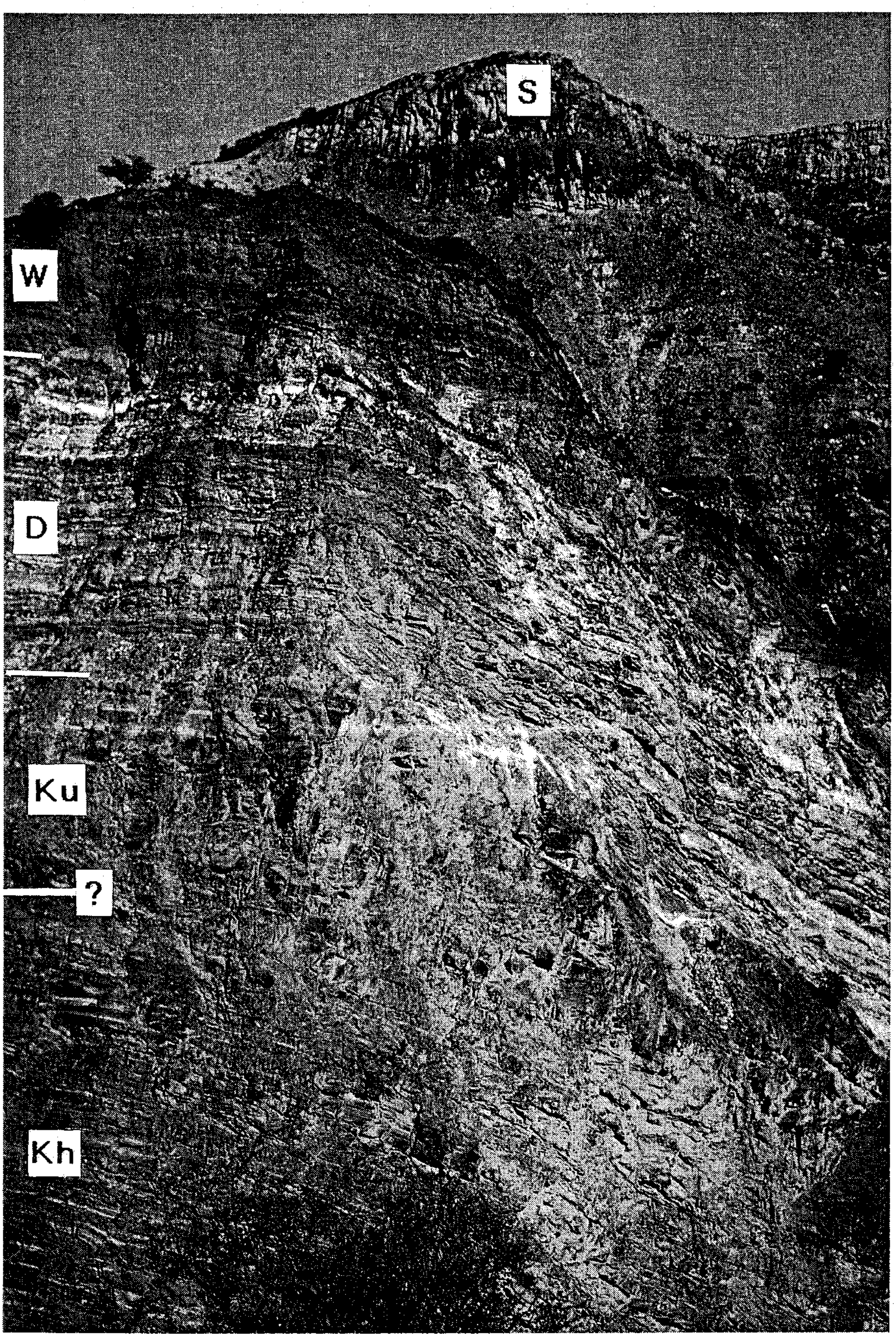


Fig. 3.4. Section of the Khewra and Kussak Formations (Early Cambrian), the Dandot and Warchha Formations (Lower Permian), and of the Sakesar Formation on top (Early Eocene). Kattha Gorge, Salt Range. (Photo: D. BANNERT).

The major part of the Salt Range Formation consists of red, gypsiferous claystone ("Salt marls") (Fig. 3.3) without any apparent bedding. Intercalated thick salt bodies (Fig. 3.4) are being mined at Khewra (32° 38'N; 73° 01'E), Warchha (32° 24'N; 71° 58'E), Kalabagh and some other localities in the Salt Range.

The middle part of the Formation contains an alternation of gypsum, dolomite, shale, siltstone and sandstone with oil-shale layers (see Chapter 7.2), particularly in the western Salt Range. The top of the Formation is formed by a gypsum layer containing high-grade oil-shale or a layer of highly altered volcanic rock ("Khewra Trap"). The thickness of the Salt Range Formation is more than 800 m at the type locality (base not exposed). In the Kohat-Potwar Foredeep the thickness locally exceeds 2,000 m as a result of secondary salt migration and accumulation induced by decollement and southward-thrusting of the overlying sedimentary sequence. The Formation is devoid of fossils. Due to its position below fossiliferous Lower Cambrian and above the metamorphic Precambrian basement, it is considered as Late Proterozoic. This is in accordance with the results of sulphur-isotope measurements carried out on gypsum samples from the top of Salt Range Formation which indicate an age of about 600 mio. years (H. A. RAZA, person. commun.). The evaporite sequence of the Salt Range Formation was deposited in a restricted, shallow-marine environment under arid conditions.

The rocks exposed around the southern margin of the Peshawar depression in the Nowshera, Gandghar and Attock-Cherat Ranges are mostly Precambrian to Devonian metasediments. The Attock-Cherat Ranges consist of three structural blocks which are bounded by thrust faults (YEATS & HUSSAIN 1987). The northern block is composed of the Precambrian **Manki-**, **Shahkot-**, **Utch- Khattak** and **Shekhai Formations**, whereas the central block is largely made up of the Precambrian **Dakhner Formation** (Fig. 3.2). These names of the Precambrian formations were initially defined by TAHIRKHELI (1970). The definition has been modified and adapted by YEATS & HUSSAIN (1987, 1989) and HYLLAND et al. (1988).

The **Manki Formation** consists of dark grey, thin-bedded argillite, slate and phyllite at least 950 m thick. The argillite and slate contain two sets of cleavage, one parallel to the bedding, the other set being the axial-plane cleavage. The metamorphic grade increases northwestward from argillite and slate to phyllite with extensive development of quartz veins (HYLLAND et al. 1988). The base of the Manki Formation is not exposed. Upward it grades into the overlying Shahkot Formation. Based on lithologic correlation with the Hazara Formation, HUSSAIN et al. (1990) considered the Manki Formation to be of Precambrian age.

The **Shahkot Formation** is exposed in the Gandghar and Attock-Cherat Ranges and consists of limestone, argillite and shale. At the base of the formation there is a 10 m thick fine- to medium- bedded cherty limestone. The argillite in the upper part contains thin, discontinuous algal limestone. The Shahkot Formation is about 300 m thick and it is conformable with the underlying Manki Formation and the overlying Utch Khattak Formation (HYLLAND et al. 1988).

The **Utch Khattak Formation** is exposed in the Attock-Cherat and Gandghar Ranges. It consists of limestone, argillite and shale 200 m to 250 m thick. The lower part of the Formation contains a 10 m to 70 m thick limestone unit that is grey, thin-bedded, fine to medium grained and in places contains stromatolites. It is overlain by dark greenish-grey, thinly-laminated argillites interbedded with grey to brown, thin-bedded shale. A conglomerate within the Formation contains clasts of the Manki and Shahkot Formations. The Utch Khattak Formation is conformable with the underlying Shahkot Formation and the overlying Shekhai Formation (YEATS et al. 1987, HYLLAND et al. 1988). The Utch Khattak and Shahkot Formations have been assigned a tentative Late Precambrian age by YEATS et al. (1987), because they are conformable with the underlying Manki Formation.

The **Shekhai Formation** is composed largely of limestone and marble interbedded with lesser amounts of quartzite and shale. The limestone ranges in colour from grey, light-brown to pink. Locally it is oolitic. In the Gandghar Range, patches of white brecciated marble are associated with igneous dykes (HYLLAND et al. 1988). The Shekhai Formation has been assigned a tentative Late Precambrian age.

In the Attock-Cherat Ranges, the central fault block consists mainly of argillite, sandstone and subordinate limestone assigned to the **Dakhner Formation** (Figs. 3.4 A, 3.4 B). This Formation has a minimum thickness of 1,000 m. The sandstone and argillite are grey to greenish-grey, thin-bedded to massive, and ripple-marked. According to HUSSAIN et al. (1990) there is a faulted lens within the Dakhner Formation that has yielded Cenomanian fossils. The Dakhner Formation is unconformably overlain by Jurassic and Cretaceous sequences. HUSSAIN (1984) and YEATS et al. (1987) have tentatively assigned a Late Precambrian age to the Dakhner Formation owing to lack of apparent correlation with fossiliferous Phanerozoic sequences, absence of fossils and absence of bioturbation in fine grained strata. According to them, the Dakhner Formation could be stratigraphically equivalent to the Manki Formation, differing only in degree of metamorphism.

North and northeast of the Peshawar Depression there is a narrow belt of metasedimentary rocks perched on the northern margins of the Indo-Pakistan crustal plate along the Indus suture zone. This belt extends from the Afghan border northeastward through Swat, Indus Kohistan, Chilas, round the Haramosh-Nanga Parbat Massif into the Astor Valley and the Kashmir Himalayas (LAWRENCE et al. 1989). These metasediments are largely crystalline schists and paragneisses, which occupy discontinuous stratigraphically-distinct wedges and thrust slices in a number of large-scale crustal nappes (see Chapter 2.25). Between the Swat and Kaghan Valleys there are six major nappes, namely the Swat Nappe, the Besham Nappe, the Hazara Nappe, the Banna Nappe and the Lower and Upper Kaghan Nappes (TRELOAR et al. 1989 a). Each of these nappes constitutes a distinct tectonostratigraphic unit (see Chapter 2.25). The basal parts of the Swat, Besham, Hazara and Lower Kaghan Nappes consist of metasediments believed to be of Precambrian age. These Precambrian complexes are unconformably overlain by variably metamorphosed cover sediments (see Chapter 4.1). At a few places, these metasediments have been intruded by Early Paleozoic granites such as the Mansehra Granite, which has yielded a Rb/Sr date of 516 mio. years (LE FORT et al. 1980). ^{40}Ar/^{39}Ar dating of the metasedimentary sequence near Besham (Besham Group) has given dates of 2,000 ± 6 mio. years, 1,950 ± 3 mio. years and 1,865 ± 3 mio. years to 1,887 ± 5 mio. years (BAIG et al. 1989 b). New ^{40}Ar/^{39}Ar dating of some of these basement rocks has indicated five pre-Himalayan metamorphic events which occurred at 2,000 ± 6 mio. years, 1,950 ± 3 mio. years, 1,865 ± 3 mio. years to 1,887 ± 5 mio. years, 650 ± 2 mio. years and 466 ± 2 mio. years (BAIG et al. 1989 b).

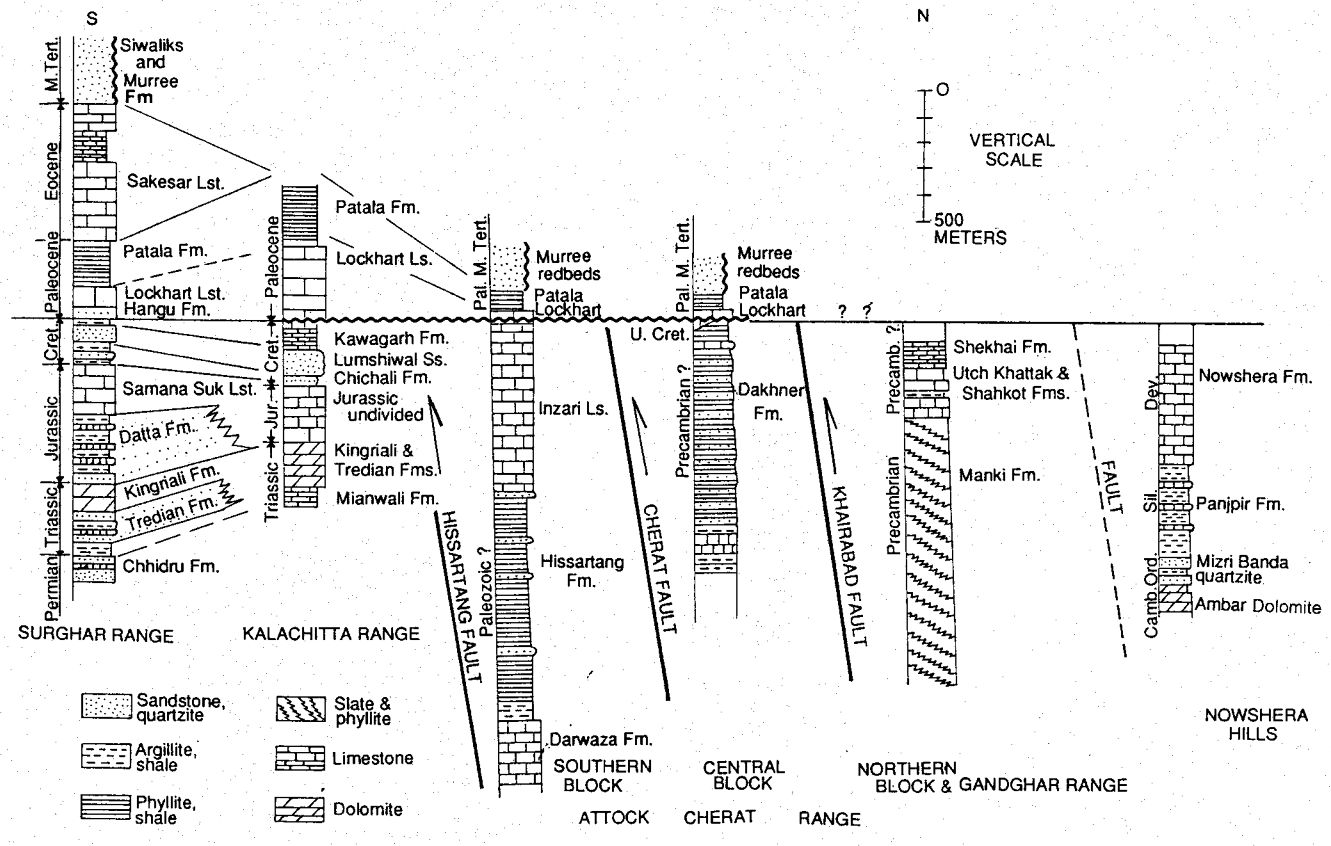


Fig. 3.4A. Sequences in the Surghar, Kalachitta, Attock-Cherat Ranges and in the Nowshera Hills (after YEATS et al. 1987, HYLLAND et al. 1988, HUSSAIN et al. 1989).

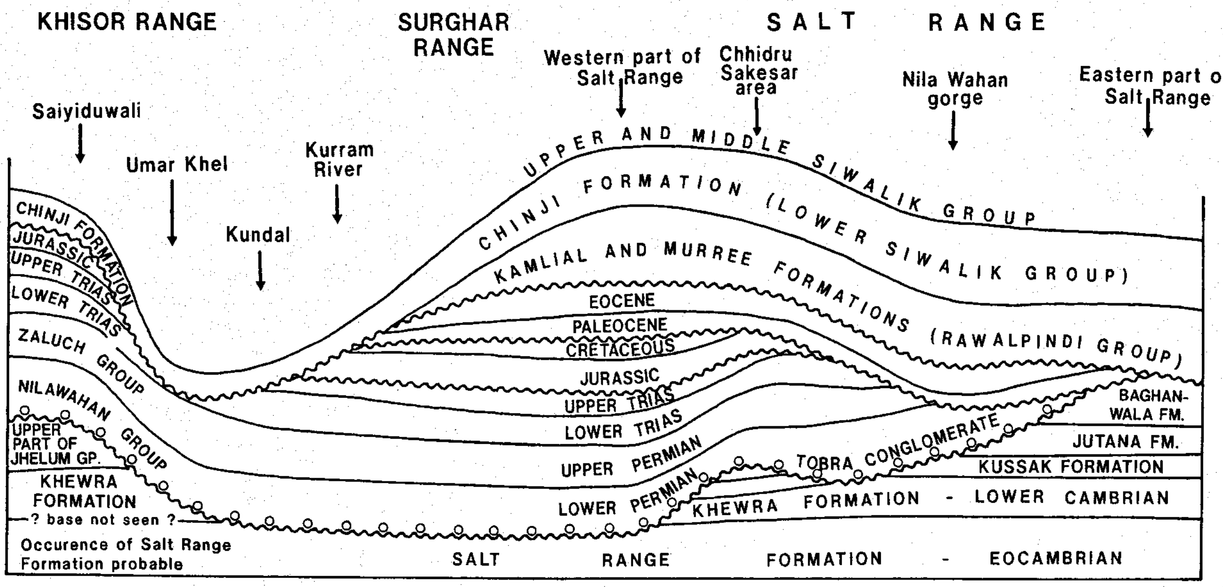


Fig. 3.4B. Diagrammatic section of the Upper Proterozoic (Eocambrian) to Tertiary sequences of the Salt Range – Surghar Range – Khisor Range (after GEE 1989).

In the Swat area, the **Manglaur Crystalline Schist**, at its type locality near Manglaur Village (34° 49'N; 72° 26'E), was identified as a Precambrian unit by KAZMI et al. (1984). It is exposed from near the Afghan border through Swat to the Besham area (LAWRENCE 1989; TRELOAR et al. 1989 a, 1989 b; DIPIETRO 1991). The Manglaur Schist constitutes the Swat Nappe and crops out as tectonized and, at places, mylonitized, non-calcareous granoblastic quartz-mica-garnet schist, which has been feldspathized and tourmalinized. There are three main lithologic varieties, namely quartz-feldspar schist, quartz-mica-kyanite schist and quartz-mica-garnet schist. Thin layers of graphitic and hornblende schists (para-amphibolite) are present (KAZMI et al. 1984). The Manglaur Schist is overlain unconformably by the Alpurai Group (see Chapter 3.24). The age of the Manglaur Schist is uncertain. Because of its resemblence with the Tanawal Formation and correlation of the Mansehra Granite with the Swat Granite Gneiss, KAZMI et al. 1984 and subsequent workers (LAWRENCE 1989, TRELOAR 1989 c, WILLIAMS 1989) have tentatively assigned a Precambrian age to the Manglaur Schist.

In the Swat area about 5 km southeast of Ilam (34° 37'N; 72° 22'E), discontinuous lenses of a calc-silicate-bearing marble unconformably rest on the Swat Granite Gneiss and the marble is unconformably overlain by the Alpurai Group. This marble unit has been named **Jobra Formation** by DIPIETRO (1990, 1991); its age is as yet not known. From its superposition between the Swat Granite Gneiss and the Alpurai Group it may be inferred to be Paleozoic.

Westward near Alpurai (34° 54'N; 72° 39'E), the Swat Nappe structurally overlies the Besham Nappe, which consists largely of sequences of the Precambrian **Besham Group** (FLETCHER et al. 1986, TRELOAR et al. 1989 b). This Group includes granitic, biotite-rich orthogneisses as well as a sequence of metasedimentary gneisses, schists metapsammites, marbles and amphibolites (see Chapter 4.1). North of Besham (34° 55'N; 72° 52'E) and below the Main Mantle Thrust (MMT), there are several hundred meters of thick quartz feldspathic mylonites and blastomylonites (LAWRENCE et al. 1983). Largely undeformed tourmaline granites intruded the gneisses and mylonites (WILLIAMS 1989).

The original relationships between the ortho- and para-gneisses of the Besham Group are not clear because most of the contacts are sheared; according to TRELOAR et al. (1989 a), it is likely that the orthogneisses formed a basement for the paragneisses. The Besham gneisses are overlain by, and imbricated with, the covering metasediments of the Karora Group. ^{40}Ar/^{39}Ar dating of the Besham Group amphibolites has given ages of 2,000 ± 6 mio. years, 1,950 ± 3 mio. years and 1,865 ± 3 mio. years to 1,887 ± 5 mio. years (BAIG et al. 1989 b). The age of the Besham Group is therefore defined as Late Archean to Middle Proterozoic.

The Besham Group is overlain by the **Karora Group** along an angular unconformity (Fig. 3.2; LAFORTUNE 1988, WILLIAMS 1989, TRELOAR et al. 1989 a). At the base there is a conglomerate bed followed by graphitic phyllite, psammitic phyllite, intraformational conglomerate, calc-pelite, banded to massive quartzite, dolomite and marble. The rocks are deformed and metamorphosed to greenschist facies. Sodic leucogranites and pegmatites intruded the Karora Group, some of which have been dated as Early to Late Palaeozoic, and on this basis, according to BAIG et al. (1989 b), the Karora Group is Middle to Late Proterozoic.

West of Besham, the Hazara Nappe crops out and is separated from the Besham Nappe by the Thakot Shear Zone (see Chapter 2.25). The Hazara Nappe consists largely of metaquartzites, metapsammites and garnet-mica schists of the **Tanawal Formation** (TRELOAR et al. 1989 a). This Formation crops out extensively in the Hazara District and unconformably overlies the Hazara Formation of Precambrian age. It is overlain unconformably by the Abottabad Formation of Cambrian age. It is intruded by the Late Cambrian Mansehra Granite (LEFORT et al. 1980), and is placed in the Late Proterozoic (WILLIAMS 1989, TRELOAR et al. 1989 a).

The **Hazara Formation** (CALKINS et al. 1975), first described as "Salt Series of Hazara" by MIDDLEMISS (1896), consists of light-grey to dark-grey, partly phyllitic slate with some intercalations of sandstone, limestone, gypsum and graphite. Based on the presence of evaporites, the epimetamorphic Hazara Formation has been correlated with the non-metamorphic Salt Range Formation by LATIF (1973). Radiometric age determinations carried out by CRAWFORD & DAVIES (1975) on two samples from the Hazara Formation, however, yielded values of 765 ± 20 mio. years and 950 ± 20 mio. years, respectively, showing that the Hazara Formation is probably older than the Salt Range Formation.

West of Balakot (34° 34'N; 73° 22'E), the Balakot Shear Zone separates the Hazara Nappe from the Lower Kaghan Nappe. The Lower Kaghan Nappe consists of a series of metapelites, schists, quartzites, marbles, metaconglomerates and pegmatites, which have been called the **Kaghan Group** (GHAZANFAR & CHAUDHRY 1986). These rocks were originally loosely correlated with the Salkhala Formation of Precambrian age (CALKINS et al. 1975, GHAZANFAR & CHAUDHRY 1985).

In the northeastern part of the Kaghan Valley, a northwest trending thrust fault, the Batal-Luat fault (MCT ?), truncates the Kaghan Group. North of this fault, higher grade metamorphic rocks such as garnetiferous calc-pelitic gneisses, pelitic gneisses, graphitic gneisses, pelitic gneisses with kyanite and sillimanite, marbles with sheet granites and amphibolite form open elongated basins and domes. These rocks have been named Sharda Group by GHAZANFAR & CHAUDHRY 1986. Previously they were referred to as the Salkhala Formation (WADIA 1930).

In the Himalayan crystalline zone between Kashmir and the Hazara area, metamorphic sediments of the **Salkhala Formation** ("Salkhala Series"; WADIA 1930) are widely distributed. Type locality is the village of Salkhala on the Kishanganga River, in Kashmir. The Formation is made up of slate, phyllite and schist with intercalated marble and quartzite beds as well as graphite layers. At the type locality in Kashmir, the Salkhala Formation is overlain by the Dogra Slate which is correlated with the Hazara Formation of the Hazara area. Hence, also the Salkhala Formation is considered as Proterozoic.

In the Nanga Parbat-Haramosh Massif (Gilgit District), a sequence of crystalline schist and gneiss has been referred to as the **Nanga Parbat Group** (MADIN 1986). The Group consists of three lithostratigraphic units. At the base in the **Shengus Gneiss**, which includes fine-grained laminated, amphibolite-grade pelitic and psammitic paragneiss with subordinate amphibolite, and calc-silicate gneiss. It is at least 5 km thick. It is overlain by the **Iskere Gneiss** which is dominantly amphibolite-grade, coarse-grained, biotite gneiss, with subordinate calc-silicate gneiss, amphibolite and biotite schist. It has a minimum thickness of 8 km. The gneiss is a plutonic rock intruded into a sequence of metasediments. It is overlain by the **Haramosh Schist** which consists of amphibolite grade biotite schist and gneiss with marble, calc-silicate gneiss and amphibolite. It may be distinguished from the Iskere Gneiss of coarse-grained biotite gneiss. The Iskere Gneiss has given a U/Pb isochron date of 1,800 mio. years on the basis of which the Nanga Parbat Group is considered to be Archaean or Early Proterozoic (MADIN et al. 1989).

3.2 Paleozoic sedimentary rocks

A correlation of Paleozoic sequences is shown on Fig. 3.2.

3.21 Cambrian

Cambrian sediments are well exposed in the Salt Range and Khisor Range; they have also been identified in the Hazara area. In the Salt Range, the Cambrian sequences have been subdivided into four Formations: **Khewra Sandstone, Kussak Formation, Jutana Formation, Baghanwala Formation.**

The **Khewra Sandstone** (SHAH 1977), previously known as the "Purple Sandstone Series" (WYNNE 1878), overlies the Late Proterozoic Salt Range Formation without any apparent disconformity. Type locality is the Khewra Gorge (32° 38'N; 73° 01'E) in the eastern Salt Range. The Khewra Sandstone is widely exposed in the Salt Range, and in the Khisor Range. It was also penetrated by drilling in the southern and eastern Kohat-Potwar Foredeep (see Chapter 7.12), as well as in the Punjab Plains south of the Salt Range and east of the Sulaiman Foredeep. The Khewra Formation consists mainly of reddish-brown to purple, thick-bedded to massive sandstone with few brown shale intercalations. The sandstone is characteristically cross-bedded, has abundant ripple marks and mud cracks, and, in places, exhibits convolute bedding. The thickness of the Khewra Sandstone is 150 m at the type locality in the eastern Salt Range, and 80 m in the Khisor Range.

Apart from rare trace fossils interpreted as trilobite trails by SCHINDEWOLF & SEILACHER (1955), the Formation is devoid of fossils. Because of its position between the Late Proterozoic Salt Range Formation and the fossiliferous Early (to Middle ?) Cambrian Kussak Formation, the Khewra Sandstone is thought to represent the basal part of the Lower Cambrian.

The **Kussak Formation** (SHAH 1977), first described as "Obolus Beds" by WYNNE (1878) and as "Neobolus Beds" by WAAGEN (1895), rests disconformably upon the Khewra Sandstone, marked by a widespread, thin conglomerate developed at the base of the Kussak Formation. Type locality is near Fort Kussak in the eastern Salt Range. The Kussak Formation is well-exposed in the Salt Range, between Jogi Tilla (32° 51'N, 73° 27'E) in the east and Chhidru (32° 33'N; 71° 46'E) in the west, as well as in the Khisor Range. It has also been encountered by wells drilled in the southeastern Potwar area and in the Punjab Plain. The formation consists mainly of grey, silty and sandy, glauconite shale with some sandstone intercalations and few black shale layers. The thickness of the formation is 75 m at the type locality, 30 m in Khisor Range, and locally more than 200 m in the southern Punjab Plain. The Kussak Formation contains brachiopods and trilobites, among them *Neobolus warthi* and *Redlichia noetlingi*, pointing to an Early Cambrian (SCHINDEWOLF & SEILACHER 1955), or early Middle Cambrian age (TEICHERT 1964), respectivelyears. The fauna, together with the glauconite content, indicates a marine depositional environment.

The **Jutana Formation** (SHAH 1977), previously named "Magnesian sandstone beds" by FLEMING (1853) and "Jutana stage" by NOETLING (1894), respectively, overlies the Kussak Formation conformably. Type locality is near the village of Jutana in the eastern Salt Range. The Formation has a distribution similar to the Kussak Formation in the Salt and Khisor Ranges as in the eastern and southern Potwar Basin, in the Mianwali Re-entrant and in the southern Punjab Plain. It is composed of cliff-forming, thick-bedded to massive, brownish-weathering, sandy dolomite and dolomitic sandstone with few shale intercalations. The thickness is 75 m – 90 m in the eastern Salt Range, and 45 m in the Khisor Range. The Formation has yielded some brachiopods, gastropods and trilobites, among them *Redlichia noetlingi* and *Pseudotheca subrugosa* (TEICHERT 1964), as well as *Cruziana* sp. (A. SEILACHER, pers. commun.). The fossils indicate a later Early Cambrian to early Middle Cambrian age.

The **Baghanwala Formation** (SHAH 1977) rests conformably on the Jutana Formation. It was first described as "Pseudomorphic Salt Crystal Zone" by WYNNE (1878), and later as "Salt Pseudomorph Beds" by HOLLAND (1926). Type locality is near Baghanwala village in the eastern Salt Range. The distribution of the Formation in surface outcrops is practically identical with that of the Kussak and Jutana Formations. In the Potwar area however, only few erosional remnants of the Baghanwala Formation have been preserved below the Permian unconformity. The Formation is also present in the subsurface of the southern Punjab Plain. The Baghanwala Formation consists mainly of reddish-brown shale and platy to flaggy sandstone characterized by an abundance of salt pseudomorphs. Ripple marks and mud cracks are common. The thickness of the formation is about 100 m at the type locality, but is commonly reduced by erosion in other parts of the Salt Range. Apart from some trace fossils, the Formation is largely devoid of faunal relics. Because of its conformable contact with the underlying Jutana Formation, it has tentatively been assigned to the Middle Cambrian. The sediments of the Formation were deposited in a lagoonal environment under arid conditions.

In the southern Khisor Range, the **Jutana Formation** is overlain conformably by the **Khisor Formation** (SHAH 1977), first mentioned as "Gypsiferous Series" by GEE (1945). Type locality is west of Saiyedwala (31° 07'N; 73° 31'E). The prevailing lithology is white to light-grey, partly dark-grey and laminated gypsum with dolomite layers and intercalations of dark-grey to black, silty, partly dolomitic shale. The thickness ranges from 100 m to 135 m. The Khisor Formation is barren of fossils. It is interpreted as an evaporitic time-equivalent of the Middle (?) Cambrian Baghanwala Formation.

In the southern Himalyan foothills of Hazara, a different Paleozoic sequence is exposed. It consists of the Abbottabad and Hazira Formation, to which a Cambrian age has been assigned.

The **Abbottabad Formation** (MARKS & ALI 1962) overlies the Precambrian Tanawal Formation unconformably. It was described by previous authors as "Below the Trias" (WAAGEN & WYNNE 1872) and "Infra-Trias" (MIDDLEMISS 1896), respectively. Type locality is the Sirban Hill near Abottabad (34° 10'N; 73° 14'E). The Formation extends from the Tarbela area (Indus River) in the west through Abottabad to Muzaffarabad and Balakot in the east and northeast. In the Abottabad area, LATIF (1970 a, 1970 b, 1974) described the Abbottabad Formation, for which he suggesed the name "Abottabad Group", as mainly consisting of thick-bedded sandstone, with some shale, siltstone and dolomite intercalations in its lower part ("Kakul Formation"). The basal unconformity is marked by a conglomerate ("Tanakki Conglomerate"). The upper part of the Abottabad Group as defined by LATIF is formed by a thick dolomite/limestone/marble sequence with few quartzitic sandstone layers ("Sirban Formation"). The marble contains phosphorite, which is being mined near Abbottabad (see Chapter 9.1). The lithology of the Abbottabad Formation shows great lateral variations. CALKINS et al. (1968) reported the presence of phyllite as well as dolomite, quartzite and conglomerate. The thickness of the Formation is about 660 m at the type locality and 900 m elsewhere. The Formation is sparsely fossiliferous. *Hyolithes* spp. and *Hypolithellus* spp. indicate an (Early ?) Cambrian age (SHAH 1977).

The **Hazira Formation** (GARDEZI & GHAZANFAR 1965) overlies the Abbottabad Formation with an apparently conformable contact. Type locality is the village of Hazira (34° 18'N; 73° 19'E); the main area of distribution is southern Hazara. The lower part of the Formation, also described as "Haematite Formation" or "Galdanian Formation" (LATIF 1970 a), is characteristically developed near Galdanian (34° 15'N; 73° 19'E) northeast of Abbottabad. It consists of purple quartzitic siltstone with some manganese oxide layers, followed by an alternation of nodular haematitic shale and sandstone, as well as quartz breccias. Locally, volcanic rocks have been observed within this part of the sequence. The upper part of the Hazira Formation is mainly composed of grey and yellowish-brown, calcareous siltstone and sandstone with earthy concretions, and some quartzite beds. The basal portion is characteristically glauconitic, whereas the middle part is phosphatic (LATIF 1970 a). The maximum thickness of the Formation is 300 m. FUCHS & MOSTLER (1972) described a small fauna of Porifera, Hyolithids and Annelids indicative of an Early (?) Cambrian age. RUSHTON (1973) reexamined the Hyolithids and sponge spicules found by LATIF in the glauconitic part of the Hazira Formation and confirmed the Cambrian age.

Cambrian rocks might also be present within the Paleozoic complex near Nowshera, Peshawar District. POGUE & HUSSAIN (1986) and HUSSAIN et al. (1989) modified and revised the stratigraphy of the Nowshera area and suggested the name "Amber Dolomite" for the oldest unit of this complex. On the basis of similar lithology they correlated it with the Cambrian Abbottabad Formation of Hazara. HUSSAIN et al. (1990) have now referred to it as **Amber Formation**. This unit is mainly composed of brownish-grey dolomite with chert lenses and some shale layers. The upper part is more massive and contains stromatolitic laminations. Dolomite pebbles are present in the basal conglomerate of the Ordovician Misri Banda Quartzite which overlies the Amber Dolomite unconformably. The thickness of the Amber Dolomite is more than 425 m (base not exposed).

In the Attock Range, according to HUSSAIN et al. (1990), the oldest Formation exposed on its southern slopes, consists of cream-coloured limestone with dolomite overlain by maroon argillite. It has been named **Darwaza Formation** (HUSSAIN et al. 1990). Its lower contact is not exposed. Its upper contact is gradational with the overlying **Hisartang Formation** (HUSSAIN et al. 1990). The Darwaza Formation is unfossiliferous and has been tentatively correlated with the Amber Formation (HUSSAIN et al. 1990).

3.22 Ordovician – Silurian

Ordovician rocks have been identified in the Paleozoic complex of the Nowshera area. The **Misri Banda Quartzite** (STAUFFER 1968 a, POGUE & HUSSAIN 1986, HUSSAIN et al. 1989, 1990) contains the trace fossil *Cruziana rugosa* indicating an Early to Middle Ordovician age. The Formation rests unconformably upon the Cambrian (?) Amber Formation. It consists chiefly of grey to pinkish, cross-bedded, feldspathic quartzite with subordinate argillite. The quartzite is cross bedded and displays ripple marks and worm burrows. The base is locally formed by a layer of conglomerate. The upper third of the sequence contains limestone layers with crinoid fragments, as well as thin beds of dark-grey to black phyllite. The Formation is 175 m thick.

In the Attock-Cherat Range a series of unfossiliferous quartzites, with argillite beds in the middle, has been named **Hisartang Formation** by HUSSAIN et al. (1989, 1990). The quartzite is white to grey and fine-grained and contains impressions of worm burrows. The argillite is dark-grey to black and laminated. This Formation has a conformable gradational contact with the underlying Darwaza Formation and is overlain conformably by the Inzari Limestone. Owing to the lithologic similarities the Hisartang Formation is correlated with the Early to Middle Ordovician Misri Banda Quartzite. Its minimum thickness is 650 m.

The Misri Banda Quartzite is overlain unconformably by the **Panjpir Formation** (POGUE & HUSSAIN 1986; HUSSAIN et al. 1989, 1990). The type locality is the Panjpir village in Mardan District. At the base there is a conglomerate with clasts of quartzite, dolomite, limestone and argillite. The Formation is largely comprised of slate and phyllite with intercalations of limestone and quartzite. It is up to 1,075 m thick. The limestone in the lower part contains crinoids, pelecypods, cephalopods and Ludlovian conodonts (HUSSAIN et al. 1990). Nautiloid fragments have been found in limestones in the upper part of the Panjpir Formation. A crinoidal limestone at the top, immediately below the Nowshera Formation of Devonian age, has yielded conodonts of Late Silurian (Pridolian) age (TALENT & MAWSON 1979). The age of the Formation has been interpreted as Middle Ordovician (?) to Late Silurian by POGUE & HUSSAIN (1986).

In the Khyber Agency, near the Afghan border, a thick series of phyllites and slates with subordinate limestone, dolomite and quartzite, intruded by basic dykes and sills, is exposed for which STAUFFER (1968 b) introduced the name "**Landikotal Formation**". Outcrops of the Formation extend from Jamrud across the border into Afghanistan. Type locality is Landi Kotal (Khyber Pass). Because of the structural complexity, the thickness of 3,300 m quoted by STAUFFER appears doubtful; the figure of 1,600 m cited by SHAH et al. (1970) might be more realistic. The Landikotal Formation has not yielded any fossils. Part of the Formation has been correlated with the "Lower Formation" of Afghanistan which contains conodonts (SHAH et al 1970) indicative of a Late Ordovician to Late Silurian (Middle Ludlovian) age. The upper part of the Landikotal Formation might correlate with the upper part of the Panjpir Formation of Nowshera.

3.23 Devonian

At Nowshera, the Late Silurian Panjpir Formation is conformably overlain by the **Nowshera Formation** (STAUFFER 1968; redefined by POGUE & HUSSAIN 1986; HUSSAIN et al. 1989, 1990). The type locality is 3.5 km north of Nowshera. The outcrops of the Formation near Nowshera have been described as a reef complex by TEICHERT & STAUFFER (1965). The core of the reef is formed by limestone rich in corals, stromatoporoids, cephalopods, gastropods and brachiopods, and is surrounded by limestone containing brecciated reef material, and sparsely fossiliferous dolomites. The Nowshera Formation as defined by POGUE & HUSSAIN (1986) includes a lower fossiliferous limestone/dolomite unit ("Nowshera Formation" of STAUFFER 1968 a), a middle unit of carbonate-cemented sandstone ("**Misri Banda Quartzite**" of STAUFFER), and an upper limestone/dolomite unit ("**Pir Sabak Formation**" of SHAH 1977), doubtfully dated as Early Carboniferous by LATIF (1970 a). The total thickness of the Nowshera Formation is quoted as 595 m by POGUE & HUSSAIN (1986). Conodont studies by MOLLOY (in TALENT & MAWSON 1979) indicate an Early Devonian age of the Nowshera Formation. Corals found in the upper part ("Pir Sabak Formation") are characteristic and indicate a (pre-Late) Devonian age (SHAH et al. 1970).

In Khyber Agency, the Ordovician/Silurian (?) Landikotal Formation is overlain, with a faulted contact, by a series of shales, quartzites, limestones and dolomites described by SHAH et al. (1970) as "**Khyber undifferentiated carbonate complex**". The series extends from Ghundi Sar (34° 03'N; 71° 21'E) in the south to Shahid Mena (34°09'N; 71° 17'E) in the north. It is highly deformed, particularly in the northern part, and is dissected by basic intrusions. Some of the limestone beds are fossiliferous and contain bryozoans, and crinoid remains. SHAH et al. (1970) correlated them with the Nowshera Formation and, hence, assigned an Early Devonian age to the Khyber undifferentiated carbonate complex.

The above carbonate complex is in tectonic contact with the **Shagai Limestone** (STAUFFER 1968 b) which is exposed between the eastern end of Khyber Pass (34° 08'N; 71° 04'E), the Shagai Fort (34° 01'N; 71° 16'E), Ali Masjid (34° 02'N; 71° 16'E) and Tauda Mela (33° 58'N; 71° 12'E). Type locality is 1 km northeast of Shagai. The unit consists of grey to black, partly brown limestone which generally is thin- to medium-bedded in the lower part and thick-bedded to massive in the upper part. The limestone is locally dolomitic and highly fractured. The top of the unit is formed by thinly-laminated limestone and sheared shale. Apart from rare, unidentifiable brachiopod remains, the Shagai Limestone is unfossiliferous. In view of its conformable contact with the overlying Late Devonian Ali Masjid Formation, it is considered as Silurian (?) to Early Devonian (SHAH et al. 1970).

The **Ali Masjid Formation** (STAUFFER 1968 b) extends all over the Khyber Agency. Type locality is the village of Ali Masjid (Khyber Pass). The Formation is characteristically composed of red-coloured shale, alternating with siltstone, sandstone, quartzite and limestone. Repeated breaks in sedimentation are indicated by thin conglomerates and lateritic beds. The total thickness of the Formation is 220 m at the type locality. West of the type section, some highly fossiliferous beds were found by SHAH (1969) which yielded a brachiopod and coral fauna indicative of a Late Devonian age. SHAH (1977) correlated the Ali Masjid Formation with the Haji Gak Formation of Afghanistan.

The **Inzari Limestone** (HUSSAIN et al. 1990) is thin- to thick-bedded, yellowish to greenish-grey and crystalline. Dendrites and stylolites are common; its upper contact is faulted. No fossils have been found. HUSSAIN et al. (1990) considered it as time-equivalent with the Early Devonian Nowshera Formation.

Fossiliferous Devonian rocks form a narrow northeast trending thrust slice which crops out between Krinj (36° 00'N; 71° 48'E) and the Broghal Pass (36° 53'N; 73° 21'E) in Chitral. Dark limestone exposed near the Broghal Pass in the Yarkhun Valley and Showar Shur yielded a rich assemblage of bryozoans and brachiopods, as well as one trilobite species (*Proetus chitralensis*), indicating an Early Devonian age (PASCOE 1959). Another locality with abundant well-preserved fossils is about 2 km southwest of Koragh (36° 13'N; 72° 10'E). Here, a unit of limestone and shale contains a variety of brachiopods and corals of Late Devonian age (PASCOE 1959).

DESIO (1959, 1966, 1975) referred to the Devonian rocks of Chitral as the **Shogram Formation.** STAUFFER (1975) divided the Devonian of Chitral into the **Charun Quartzite**, (at the base) followed by **Kuragh Dolomite** and **Shogram Quartzite.** The Charun Quartzite is white, medium-grained, up to 100 m thick and contains some brachiopods (STAUFFER 1975). The Kuragh Dolomite is a mainly massive, crinoidal dolomite; it is overlain by bedded dolomite with fossiliferous dolomitic limestone with beds of brown-weathering dolomitic quartzose sandstone, calcareous black shale and few beds of tuff. According to CALKINS et al. (1981) the dolomitic limestone has yielded rugose corals (*Hexagonaria* sp. cf. *H. Rohrinsis glinski*, *Tabulophyllum* sp., *Disphyllum* or *Actinophyllum* sp.) of Devonian age.

The Shogram Quartzite is massive, cross-bedded and fine to medium-grained.

3.24 Carboniferous – Permian

In the northern montane area and in the Khyber Agency, a number of formations are observed to which an undifferentiated Carboniferous to Permian age has been assigned. In the Khyber Agency, the Upper Devonian Ali Masjid Formation is overlain conformably by the **Khyber Limestone** (STAUFFER 1968 b, GRIESBACH 1892, HAYDEN 1898). Type locality is the village of Ali Masjid (Khyber Pass). It consists mainly of thick-bedded limestones, marbles and massive dolomites, locally with minor shale intercalations. The middle part of the Formation contains some limonite-rich, arenaceous beds which might indicate a disconformity (SHAH et al. 1970). To the north and west of the type section, the upper part of the Formation is intruded by basic dykes and sills. At Tauda Mela and Misri Khel (33° 56'N; 71° 17'E), the Khyber Limestone is intercalated with shale and is highly fossiliferous. The fauna collected from the upper part of the Formation includes *Pseudovermiporella* sp., *Nodosaria* sp., *Geinitzella* spp., *Glomospirella* sp., *Robuloides* sp., *Palaeotextularia* sp., and *Frondilina* sp., and indicates a Permian age (SHAH et al. 1970).

In the hill ranges northeast of Nowshera in the Rustam (34° 20'N; 72° 19'E) area, a sequence of argillites with subordinate limestone, quartzite and conglomerate overlies the Nowshera Formation. It has been named **Jafar Kandao Formation** by POGUE &

HUSSAIN (1986). The basal unconformity is marked by a discontinuous conglomerate bed. The Formation is overlain by greenschist. According to POGUE et al. (1992), latest Devonian to Early Mississippian and Late Pensylvanian conodonts have been found in limestone lenses in this Formation. Thus it is Carboniferous in age.

Northeast of Nowshera in the Swat area, several hundred meters of unfossiliferous siliceous schist, calcareous quartz-mica-garnet schist, marble and para-amphibolite overlie unconformably the Swat Granite Gneiss. This sequence was named **Alpurai Schist** (Group) by KAZMI et al. (1984, 1986). According to these authors, these rocks could have occurred anytime during Paleozoic or Mesozoic. This Group forms the cover of the Precambrian Manglaur Schist and is a tectonostratigraphic component of the Swat nappe (TRELOAR et al. 1989 a, 1989 b). The Alpurai Schist extends over a large area (AHMAD et al. 1987, LAWRENCE et al. 1989). DIPIETRO (1990, 1991) has correlated a number of other lithostratigraphic units with the Alpurai Schist, and has referred to them as **Alpurai Group**. His Alpurai Group includes the Marghazar, Kashala, Saidu and Nikanai Ghar Formations.

The **Marghazar Formation** consists of garnetiferous schist, amphibolite, hornblende schist, psammitic schist and phlogopite marble. It overlies the Manglaur Formation and Swat Granite Gneiss unconformably (c.f. Alpurai Schist of KAZMI et al.). The Marghazar Formation is overlain by the calcareous schists of the Kashala Formation followed by the Saidu Schist and Nikanai Ghar Formations. The Kashala Formation has yielded Late Triassic (Carnian) conodonts (POGUE et al. 1992) and, therefore, at least the sequence above the Maghazar Formation of DIPIETRO (1990, 1991) is Mesozoic in age. The Marghazar Formation is tentatively considered to be of Carboniferous age (POGUE et al. 1992).

East of Besham, near Banna Village (34° 54'N; 73° 04'E), the Banna Nappe is mostly a series of marble, slate, graphitic schist and chlorite schist which has been referred to as **Banna Formation** (TAHIRKHELI 1979, TRELOAR et al. 1989 a, 1989 b).

Farther eastward, in the upper Kaghan Valley, calcareous garnet-kyanite-bearing schist, marble and amphibolite of the **Sharda Group** (GHAZANFAR et al. 1986) are exposed south of the MMT and form a thrust slice between the north dipping Batal thrust and the MMT (TRELOAR 1989 b). These rocks are similar to the Alpurai Schists. According to TRELOAR (1989 a), it is likely that the cover sediments of the Sharda Group, the Banna Formation and the Alpurai Schists may correlate.

Around the apex of Hazara Syntaxis, sediments and volcanic rocks are exposed which were described as Panjal System by LYDEKKER (1878), and Volcanic Greenstone and Agglomerate Slate by MIDDLEMISS (1910). CALKINS et al. (1969) subdivided these rocks into the **Panjal Formation**, formed by moderately metamorphic lava flows and tuffs ("greenstones"), and the **Agglomerate Slate**, consisting of black, carbonaceous shale, slate and phyllite as well as quartzose, agglomeratic sandstone. CALKINS et al. (1969) have, however, applied the name Panjal Formation to include both the units and have not discussed their contact relations or superposition. They are considered as of Carboniferous to Permian age, based on the determination of rare fossils by HOLLAND (1926).

The Tethyan Belt (see Chapter 2.25) in the Chitral and Gilgit region contains a series of metasediments, believed to be largely Permo-Carboniferous in age. HAYDEN (1915) introduced the name "Sarikol Slate" for a sequence of slates extending from the Chinese border through Gilgit Agency to Chitral and eastern Afghanistan. DESIO (1959, 1966, 1975), and PUDSEY et al. (1985) have referred to these rocks as "Lun shales". STAUFFER (1975) and CALKINS et al. (1981) have followed HAYDEN and described this unit as **Sarikol Shale** which is more in conformity with the Pakistan stratigraphic code. In Chitral, the Sarikol Shale (black slates and shales with subordinate quartzite and some limestone beds) is well-exposed along the Mastuj River near the village of Shogram (36° 09'N; 72° 07'E) near Reshun, from where Devonian (?) nautiloids have been described by TIPPER (in PASCOE 1924). Near Koragh, the Sarikol Shale overlies Late Devonian (Frasnian) rocks and underlies the "Pamir Limestone", which contains Triassic fossils (HAYDEN 1915). South of Pasti (36° 06'N; 71° 56'E), the Sarikol Shale overlies Middle to Upper Devonian rocks whereas north of Pasti it is overlain conformably by limestone and shale which contain Permian fusulinids (CALKINS et al. 1981). TALENT et al. (1979) have reported early Devonian fossils from both sides of the Shogram Fault and, according to them, the Lun shales belt of DESIO (1966) can now be shown to be of Early Devonian age. According to PUDSEY et al. (1985) these shales range from Early Devonian to at least Permian in age.

In the Mastuj (36° 16'N; 72° 31'E), Yasin (36° 22'N; 73° 21'E), Ishkoman (36° 32'N; 73° 49'E) and Hunza (36° 20'N; 74° 35'E) areas, north of the Main Karakorum Thrust (MKT), a thick sequence of slate, limestone, quartzite, conglomerate, schist, marble, gneiss, and volcanics is exposed and has been named **Darkot Group** by IVANAC et al. (1956). The Group forms two east-west trending, long belts (see Chapter 4.2). The Darkot Group has yielded bryozoans, forams, brachiopods, crinoids, corals and gastropods from a few widely scattered localities and has been assigned a Permo-Carboniferous age by IVANAC et al. (1956).

Subsequent workers have subdivided the Darkot Group into a number of separate units. STAUFFER (1968 c) named the rocks exposed south of the Karakorum Granodiorite in the Hunza Valley as the **Baltit Group**, whereas DESIO (1963, 1964) had already named them the **Dumordo Formation**. The latter name should have priority according to the stratigraphic code of Pakistan. This Formation consists largely of garnet-staurolite schist, garnet-mica schist, garnet amphibolite, crystalline marble and micaceous quartzite with scattered layers and lenses of biotite gneiss. Its contact with the Karakorum Granodiorite is partly gradational and partly intrusive. No fossils have been found in the Dumordo Formation. STAUFFER (1968 c) has tentatively placed it in the Permo-Carboniferous whereas TAHIRKHELI (1982) correlated this Group with his Chitral Slates and placed it in the Precambrian – Lower Paleozoic.

In the Hunza Valley the Dumordo Formation is exposed along an overturned anticline and is faulted against the **Chalt Formation** (DESIO 1963, 1964; DESIO et al. 1972; STAUFFER 1968 c; GANSSER 1980). The Chalt Formation consists of dark-grey quartz-biotite schist with subordinate quartzite, marble and conglomerate. Near Sandi Village (36° 25'N;73° 24'E), about 80 km west of Chalt (36° 16'N; 74° 20'E), poorly preserved bryozoans, *Fenestella* and *Rhombopora* cf., *Lepidodendroides* MEEK were found, along with a large, crushed productid and crushed coral specimen (IVANAC 1956, STAUFFER 1968 c). On this evidence, the Chalt Formation has been assigned a Permo-Carboniferous age.

North of the Karakorum Granodiorite a thick sequence of dark-grey and black slates with intercalations of dark-grey limestone and yellowish grey quartzite has been named **Passu Slate** (SCHNEIDER 1957, DESIO 1963). The contact of the slate with the Karakorum Granodiorite is sharp and intrusive (STAUFFER 1968 c); however, according to TAHIRKHELI (1982), it is a "tectonic contact". North of Passu Village (36° 28'N; 74° 53'E), crystalline dolomite, quartzite, and dark slate (the Triassic Gujhat Dolomite of DESIO 1963, 1964) are faulted into the Passu Slate. Based on bryozoans, forams and brachiopods found near Khaibar Village, the Passu Slate is assigned a Permo-Carboniferous age (IVANAC 1956, STAUFFER 1968 c).

About 20 km north of Passu there is a faulted sequence of dark argillites with thin limestone-dolomite intercalations that is underlain by light-coloured, thick-bedded to massive sandstone with slate intercalations which has been named **Gircha Formation** (DESIO 1963, 1964). According to TAHIRKHELI (1982), the calcareous part of the sequence contains brachiopods, corals, bryozoans and foraminifera of early Permian age.

Northwards, the Gircha Formation is followed by outcrops of the **Killik Formation** (DESIO 1963, 1964). This Formation consists of 200 m of limestone and dolomite with thin partings of light grey arenaceous slate and quartzite (TAHIRKHELI 1982). On the basis of crinoidal stems found in this Formation, DESIO (1966) has given it a Devonian – Early Carboniferous age and he correlated it with the Shogram Formation of Chitral.

A monotonous series of dark grey slate and phyllite with siliceous and calcareous intercalations is exposed in the uppermost part of the Hunza Valley. These rocks have been named **Misghar Slates** (DESIO 1963, 1964). This Formation is about 3,500 m thick and is commonly intruded by sills and dykes of dolerite, gabbro, pegmatite, aplite and quartz-syenite (TAHIRKHELI 1982). No fossils have been so far reported from this Formation and it is tentatively referred to the Paleozoic.

On the northern margin of the Shigar Valley of the Skardu District interbedded layers of slate and marble are exposed and these have been named as **Daltumbore Formation** after the stream Daltumbore Lungma (HANSON 1989). The metamorphic grade increases northwestward and the slates are metamorphosed to garnet-biotite schists. Previously, HANSON's Daltumbore Formation was divided into three units by DESIO (1963, 1964) and ZANETTIN (1964), namely the Lugma slates, the Daltumbore mica-schist and the Askore amphibolite. BROOKFIELD & GUPTA (1984) reported Permian brachiopods, crinoids and bryozoans in the limestone beds, and, according to HANSON (1989), Mississippian conodonts have been found by R. TIRRUL, and horn corals of probable Devonian age found by T. ALLEN. The Daltumbore Formation is thus believed to be of Permo-Carboniferous age.

The Salt Range in northern Punjab is one of the classical areas in the world where a practically complete Permian sequence is developed and perfectly exposed (Fig. 3.5). The Permian is, here, subdivided into two Groups: the predominantly clastic **Nilawahan Group** and the mainly calcareous **Zaluch Group**. The boundary between the Upper Permian and the Lower Triassic has been the subject of intensive special studies (KUMMEL & TEICHERT 1966, 1970).

The **Nilawahan Group** consists of four Formations: **Tobra Formation, Dandot Formation, Warchha Sandstone**, and **Sardhai Formation.**

The **Tobra Formation** (SHAH 1977) was formerly correlated with the "Talchir Boulder Beds" (GEE, in PASCOE 1959) and later described as "Salt Range Boulder Beds" by TEICHERT (1967). The Formation rests unconformably upon different Cambrian

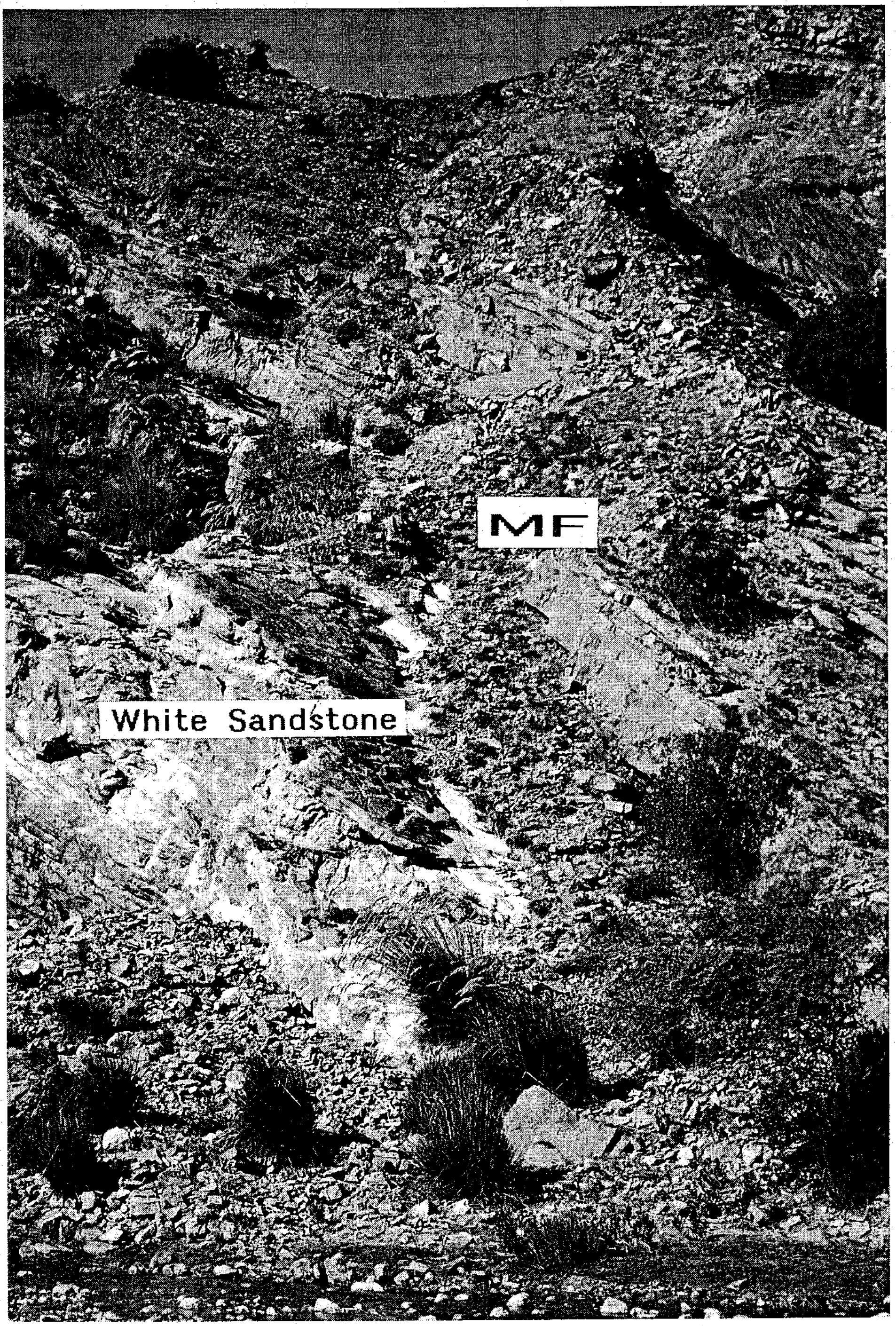


Fig. 3.5. Section of the Permian/Triassic boundary. The top of the sediments of Late Permian age are white-weathering sandstones, followed by the sequence of the Mianwali Formation (MF). Nammal Gorge, western Salt Range (Photo: D. BANNERT).

Formations or the Salt Range Formation, respectively (Fig. 3.6). Type locality is the village of Tobra (32° 40'N; 72° 59'E), north of Khewra, in the eastern Salt Range. The Formation is exposed throughout the Salt Range, as well as in the Khisor Range. It was also encountered by wells drilled in the Kohat-Potwar area, Mianwali Re-entrant and

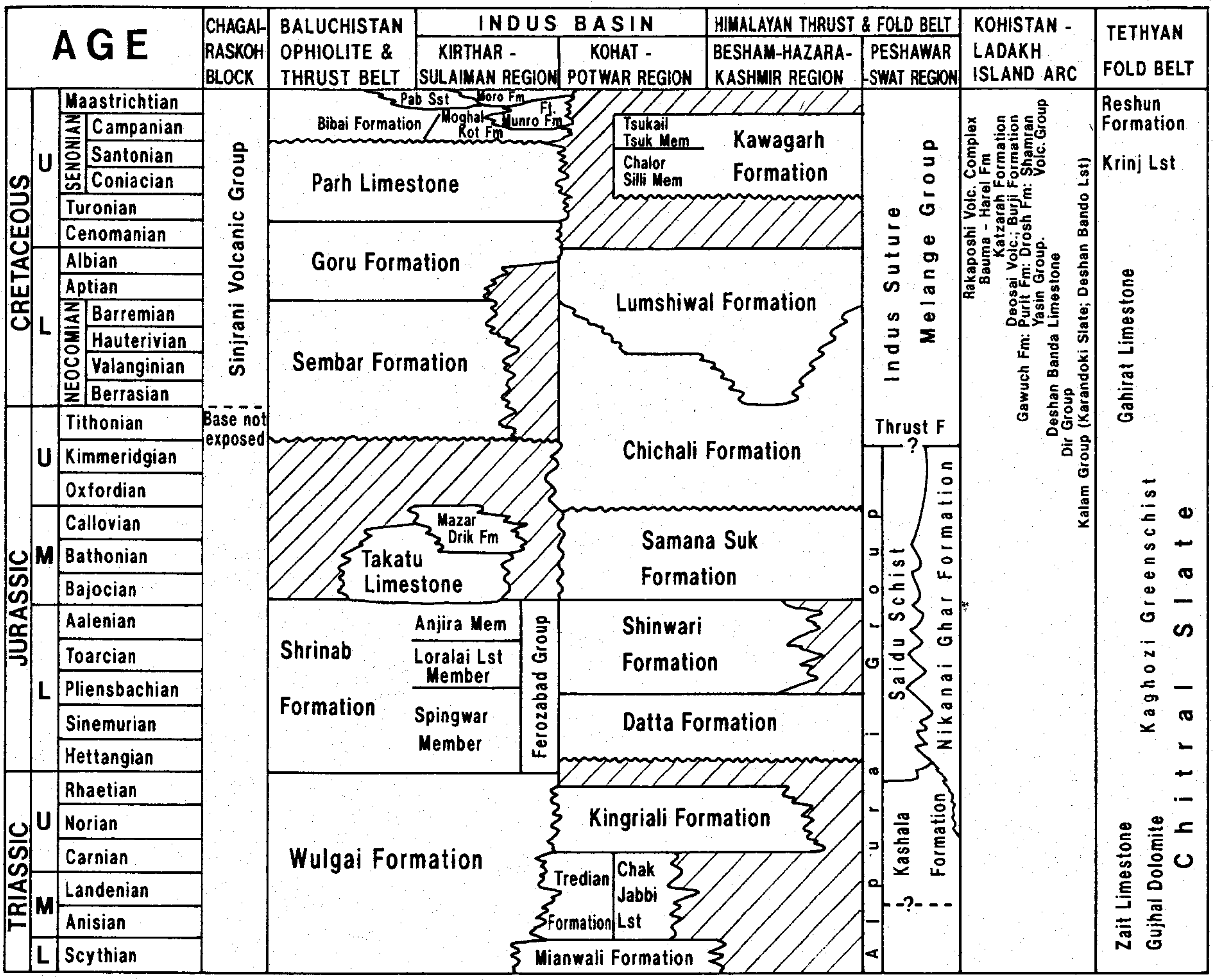


Fig. 3.6. Correlation of the Mesozoic sequences.

Marwat Range, as well as along the shallow eastern flank of the Sulaiman Foredeep. In the eastern Salt Range, the Tobra Formation consists mainly of polymict conglomerates with pebbles and boulders of igneous, metamorphic and sedimentary rocks. Based on the observation of polished and scratched boulders, TEICHERT (1967) interpreted the Tobra conglomerate as a tillite. The thickness of the Formation is 20 m at the type locality. In the western Salt Range, the Tobra Formation is developed in a distinctly different facies. Dark-grey to black, diamictic mudstones with interspersed clasts of sand-grain size to boulder size prevail. The facies is interpreted as fluvioglacial. The maximum thickness (120 m - 130 m) was observed in Zaluch Nala (32° 47'N; 71° 38'E). Thin coal beds are locally developed at the top of Tobra Formation, a few meters below the base of Warchha Sandstone. The Tobra Formation contains ostracods and freshwater bivalves (REED 1936), as well as floral remains including *Glossopteris* and *Gangamopteris*. On the basis of *Striatopodocarpites* and *Protohaploxypinus*, BALME (in TEICHERT 1967) assigned an Early Permian age to the Formation.

The Tobra Formation is overlain conformably by the **Dandot Formation** (SHAH 1977), previously known as "Olive series", "Eurydesma beds" and "Conularia beds" (WYNNE 1878), lower part of "Speckled sandstone" (WAAGEN 1879), or "Dandot

Group" (NOETLING 1901). Type locality is the village of Dandot (32° 40'N; 72° 58'E), northeast of Khewra, in the eastern Salt Range. The Formation is well represented in the eastern and central Salt Range, but is not developed in the western Salt Range and Khisor Range.

In the eastern Salt Range, the Dandot Formation mainly consists of dark greenish-grey, splintery shale and siltstone with intercalated sandstone, whereas in the central Salt Range greenish-grey to black, carbonaceous shales with sand flasers alternate with cross-bedded sandstones (Kattha-Pail road). The Formation contains a rich fauna of brachiopods *Discina*, *Martiniopsis*, *Chonetes*, bivalves (*Eurydesma*), gastropods, pteropods (*Conularia*), bryozoans and ostracods, as well as spores. On the basis of its faunal content and its gradational contact with the underlying Tobra Formation, the Dandot Formation has been dated as Early Permian (TEICHERT 1967).

The depositional environment is marine in the eastern Salt Range and becomes shallower toward the west (tidal-flat facies in central Salt Range). The thickness of the Dandot Formation is 45 m – 50 m in the east (Makrach Nala 32° 39'N; 72° 52'E) and decreases toward the central part of the Salt Range.

The **Warchha Sandstone** (HUSSAIN 1967) rests conformably upon the Dandot Formation. It represents the middle part of the "Speckled Sandstone" of WAAGEN (1879) and the lower part of the "Warchha Group" of NOETLING (1901). Type locality is the Warchha Nala in west-central Salt Range. The Warchha Sandstone is widely exposed in the Salt Range and the Khisor Range. The sandstone is generally thick-bedded to massive, reddish-brown, cross-bedded, medium to coarse-grained and arkosic. Intercalated purple to dark-grey shale layers reach a thickness of several meters each. In the western Salt Range, reddish-brown to dark-brown sandy shale with white or reddish sandstone layers prevail. In Khajji Wahan (32° 35'N; 71° 50'E), thin shaly coal beds are developed at the base of the Formation. The Warchha Sandstone is unfossiliferous. It is considered as Early Permian because of its position between the fossiliferous Early Permian Dandot and Sardhai Formations. The sediments of the Formation are interpreted as fluviatile, deposited in extended alluvial flats. The thickness of the Warchha Sandstone reaches 150 m – 165 m in the Salt Range and 120 m in the Khisor Range. In the Kohat-Potwar Foredeep, the thickness generally increases from the southeast to the northwest.

The Warchha Sandstone has a transitional contact with the overlying **Sardhai Formation** (GEE 1964, in SHAH 1977) which is an equivalent of the "Lavender Clays" of WYNNE (1878) and of the upper part of the "Warchha Group" of NOETLING (1901). Type locality is the Sardhai (Sohal) Nala (32° 41'N; 72° 43'E) in the eastern Salt Range. The Formation has an areal distribution similar to the Warchha Sandstone. It is truncated below younger transgressions in the eastern and southeastern parts of the Kohat-Potwar Foredeep. The prevailing lithology in the eastern and central Salt Range is bluish-grey, purple or reddish claystone which becomes dark-violet to black toward the western Salt Range. Plant remains and fish scales have occasionally been found. In the Khisor Range, the claystone contains layers of argillaceous, fossiliferous limestone which have yielded bryozoans and brachiopods (e.g. *Anastomopora* sp., *Fenestella* sp., *Athyris*, *Spirifer*) indicative of an Early Permian age (HUSSAIN 1967). The palaeoenvironment is interpreted as mainly terrestrial, partly lagoonal, with marine incursions which become more frequent toward the west. The thickness of the Sardhai Formation is 40 m at the type section and 60 m in the western Salt Range (Zaluch Nala), increasing toward the northern and western parts of the Kohat-Potwar area.

The **Zaluch Group** is subdivided into three formations, distinguished from each other by differences in the proportion of limestone. These are the Amb Formation, Wargal Limestone, and Chhidru Formation.

The **Amb Formation** (TEICHERT 1966), first described as "Lower Productus Limestone" by WAAGEN (1879) and subsequently as "Amb Sandstone Beds" by the same author (1889, 1891), overlies the Sardhai Formation disconformably. The type section is 5 km southwest of the village of Amb (32° 31'N; 71° 56'E) in the west-central Salt Range. The Zaluch Nala and Chhidru Nala (31° 33'N; 71° 46'E) in the western Salt Range are additional reference sections. Exposures of the Formation extend from the central Salt Range in the east to Khisor Range in the west. In the eastern Salt Range and southeastern Kohat-Potwar area, the Amb Formation has been truncated by the Paleocene transgression. The prevailing lithology is a highly fossiliferous, calcareous sandstone alternating with sandy limestone and dark-grey, locally black and carbonaceous shale. Thin coal beds are developed in the vicinity of the Amb Village. The Amb Formation contains abundant floral remains, including *Glossopteris* and *Gangamopteris* (BALME 1970), and a rich fauna including foraminifera, bryozoans, brachiopods, pelecypods, gastropods, cephalopods and ostracods (WAAGEN 1879, 1889, 1891; DUNBAR 1933; REED 1941; PASCOE 1959; TEICHERT 1966; KUMMEL & TEICHERT 1970; Pakistani-Japanese Research Group 1985). The brachiopods include different species of *Orthotichia, Cleiothyridina, Neochonetes, Derbyia, Dictyoclostus, Marginifera, Spirifer, Neospirifer, Spirigerella, Strophalosia,* and *Dielasma*. The fusulinids *Monodiexodina kattaensis* and *Codonofusiella laxa* indicate an Early Permian (Late Artinskian) age. The rich fauna of the calcareous sandstone and limestone proves a shallow to very shallow marine palaeoenvironment, probably with intermittent periods of paralic or lacustrine conditions during which the carbonaceous shale and coal were deposited. The Formation is as much as 80 m thick in the Salt Range and 40 m – 50 m in the Khisor Range.

The Amb Formation is disconformably overlain by the **Wargal Limestone** (TEICHERT 1966), equivalent of the "Middle Productus Limestone" of WAAGEN (1879) and the "Wirgal Group" of NOETLING (1901). The Formation is widely exposed in the central and the western Salt Range, and in the Khisor Range. The Formation is mainly formed by grey, medium or thick-bedded to massive, partly sandy limestone and dolomite with few, thin intercalations of dark-grey to black shale. The Wargal Limestone is highly fossiliferous. It contains an abundance of brachiopods, trilobites, pelecypods, gastropods, ammonoids, nautiloids, echinoids, corals, bryozoans, sponges, foraminifera, ostracods, conodonts and fish remains, as well as algae and spores (WAAGEN 1879-1891, REED 1944, RAO & VERMA 1953, GRANT 1966, TEICHERT 1966, KUMMEL & TEICHERT 1970, Pakistani-Japanese Research Group 1985). Among the brachiopods are *Enteletes, Derbyia, Waagenites, Waagenoconcha, Richthofenia, Oldhamina, Linoproductus, Spirigerella, Costiferina, Chonetella, Cleiothyridina, Phricodothyris, Netothyris, Hemiptychina, Terebratuloidea, Kiangsiella, Uncinunellina,* and *Callispirina*. The trilobites are represented by *Kathwaia capitorosa* and *Ditomopyge fatmii*; the ammonoids include *Xenodiscus* and *Pseudogastrioceras*. Corals are rare to common, and include *Wentzelella, Wentzelellites, Iranophyllum, Sinopora* and *Michelinia*. The fusulinids include different species of *Reichelina* as well as *Codonofusiella, Nanlingella, Nankinella, Sphaerulina, Chusenella* and *Schubertella*. The conodonts are represented by *Iranognathus, Hindeodus* and *Gondolella*.

On the basis of its faunal content, the Wargal Limestone has been dated as Late Permian (late Murgabian to early Dzhulfian). The palaeoenvironment is interpreted as generally shallow marine, with the exception of a few strata which might have been deposited under deeper water conditions (Pakistani-Japanese Research Group 1985). The thickness of the Wargal Limestone is 180 m – 200 m in the Salt Range and 150 m in the Khisor Range.

The **Chhidru Formation** (DUNBAR 1933) which represents the "Upper Productus Limestone" of WAAGEN (1879) and the "Chhidru Group" of NOETLING (1901), respectively, overlies the Wargal Limestone with a conformable, transitional contact. Type section is Chhidru Nala in the western Salt Range. The Formation is exposed in the central and western Salt Range as well as in the Surghar Range and the Khisor Range. In the southern and eastern parts of the Kohat-Potwar area, it is missing under the Paleocene unconformity. The Chhidru Formation is less massive and more sandy than the Wargal Limestone. It consists of dark-grey, sandy shale at the base, overlain by calcareous sandstone and sandy limestone. The top of the Formation is formed by a characteristic white sandstone layer as much as 5 m thick (Fig. 3.5). The total thickness of the Formation ranges from 75 m to 85 m.

The Chhidru Formation contains abundant brachiopods and gastropods and subordinate microfossils. The fauna has been described in detail by KUMMEL & TEICHERT (1970) and the Pakistani-Japanese Research Group (1985). It includes the following genera:

Brachiopods:	*Aulosteges, Callispirina, Chonetella, Cleiothyridina, Crurithyris, Derbyia, Dielasma, Enteletes, Hemiptychina, Hustedia, Kiangsiella, Linoproductus, Lyttonia, Marginifera, Martinia, Megasteges, Neospirifer, Oldhamina, Orthotichia, Richthofenia, Spinomarginifera, Spiriferella, Spirigerella, Strophalosia, Waagenites, Waagenoconcha, Whitspakia.*
Gastropods:	*Bellerophon, Euphemites.*
Pelecypods:	*Entolium, Neoschizodus, Permophorus, Palaeolima, Schizodus, Crytorostra.*
Ammonoids:	*Cyclolobus, Eumedlicottia, Episagoceras, Stacheoceras, Xenodiscus.*
Bryozoans:	*Dybowskiella, Hexagonella, Geinitzella, Stenopora, Fenestella, Polypora.*
Fusulinids:	*Codonofusiella, Reichelina, Nanlingella, Nankinella* in association with *Colaniella* and other smaller foraminifera.

Stratigraphic analyses indicate that the Chhidru Formation is most probably of Late Dzhulfian age, and that the uppermost part of the Permian (Changhsingian, Dorashamian) is missing within the Salt Range section (Pakistani-Japanese Research Group 1985). The abundance of terrigenous clastic material in the Chhidru Formation indicates a near-shore environment and/or an uplift of the source area. The white sandstone forming the top of the Formation was subjected to subaerial erosion (KUMMEL & TEICHERT 1970).

Equivalents of the Permian Zaluch Group have also been reported from the central parts of the Sulaiman and Kirthar Ranges (VREDENBURG 1904, 1909 a; WILLIAMS 1959, Hunting Survey Corp. 1960, SOKOLOV & SHAH 1965). Near Wulgai (30° 39'N; 67° 29'E), Ghazaband (30° 20'N; 66° 50'E) and Kalat (29° 03'N; 66° 36'E), dark-grey to black, crystalline limestone, partly associated with slate, have yielded brachiopods such as *Athyris, Dielasma, Marginifera* and *Notothyris*, as well as fusulinids, crinoids, stromatopores and algae (SHAH 1977).

3.3 Mesozoic sedimentary rocks

Mesozoic sedimentary rocks (Fig. 3.6) crop out extensively in the Kirthar-Sulaiman region and the Kohat-Potwar-Salt Range region of the Upper Indus Basin, and in the West Pakistan Foldbelt (see Chapter 2.23). They also form significant components of the tectonostratigraphic sequences in the Himalayan thrust and fold belt, the Kohistan Island Arc Complex (see Chapter 2.253) and the Tethyan Belt (see Chapter 2.25). In the Lower Indus Basin (Kirthar-Sulaiman region), the Mesozoic rocks are largely marine, calcareous and argillaceous and several thousand meters thick (Fig. 3.1). Northward, in the Upper Indus Basin (Kohat-Potwar-Salt Range), they decrease in thickness to about one thousand meters and include a substantial amount of terrestrial deposits. In the Chagai area of Baluchistan, as well as in the Kohistan Island Arc Complex, the Mesozoic sedimentary sequence consists largely of Cretaceous volcanic and sedimentary rocks. The Himalayan Thrust and Fold Belt which is mainly a series of disjointed, overlapping slices of thrusts and nappes, contains Mesozoic metasediments locally interbedded with volcanics or covered with obducted masses of ophiolites and mélanges. The Mesozoic metasediments form the cover of the basement rocks. Further northwards in the Tethyan Belt, Mesozoic metasediments crop out in the form of extensive east-west trending arcuate thrust blocks, imbricated with earlier metasedimentary sequences.

3.31 Triassic

The Triassic sedimentary sequence in Pakistan is rather restricted in its thickness and extent. Triassic rocks assigned to the Wulgai Formation are present in tectonised blocks in the Kirthar-Sulaiman region in Baluchistan and the Himalayan Thrust and Fold Belt. Triassic rocks belonging to the Mianwali Formation, Tredian Formation, Chek Jabbi Limestone and Kingriali Formation are exposed in the Kohat-Potwar-Salt Range region of the Upper Indus Basin. The Himalayan Thrust Belt in the Swat-Mardan region contains outcrops of the **Kashala** and **Nikanai Ghar** Formations which are the Triassic components of the Alpurai Group. East of this region in the Hazara area, the Triassic sequence is missing, and the Jurassic rocks unconformably overlie the Paleozoic sequence. In the Chitral area of the Tethyan Belt (see Chapter 2.25), the **Zait Limestone** is exposed in the Mastuj Valley.

The **Wulgai Formation** (WILLIAMS 1959; Fig. 3.6) is exposed in the West Pakistan Foldbelt and has been encountered also in wells drilled in the Lower Indus Basin. It consists of indurated dark-grey mudstone and shale with intercalations of thin limestone and calcareous mudstone and sandstone. Previously these rocks were described under different names – Alozai Group (Wulgai section near Muslimbagh), Shrinab Formation (Khuzdar section) and Winder Group (Lasbela area) by Hunting Survey Corp. (1960). The thickness of the Wulgai Formation in the type section at Wulgai (30° 39'35"N; 67° 29'25"E) is estimated at 1,180 m (WILLIAMS 1959), whereas, according to SOKOLOV & SHAH (1965), the total thickness is 985 m. The lower contact of the Wulgai Formation with Permian beds is tectonically disturbed in the Wulgai area but it is conformable in the Shrinab section (Hunting Survey Corp. 1960, SOKOLOV & SHAH 1965). Its upper contact with the Jurassic sequence is transitional (FATMI 1977). *Columbites* sp., has been reported from the lower part of the Formation whereas *Halorites* sp., *Jovites* sp., *Pararcestes* sp., *Arietoceltites* sp., *Halobia* sp. and *Monotis salinaria* have been obtained from the upper part. According to FATMI (1977), these fossils indicate an Early and Late Triassic age.

The rocks included in the **Mianwali Formation** (KUMMEL 1966) were previously known as "Mianwali Series", "Ceratite beds" and other names (GEE 1945, PASCOE 1959, WAAGEN 1879,1895). This Formation consists mainly of marl, limestone, sandstone, siltstone and dolomite. It is exposed in the Khisor Range, Surghar Range and the western part of the Salt Range. Farther eastward it wedges out as a result of the erosion that preceded Tertiary deposition. This Formation has been divided into the **Kathwai Member**, the **Mittiwali Member** and the **Narmia Member** (KUMMEL 1966).

The Mianwali Formation overlies the Chhidru Formation of Permian age (GEE 1989) conformably, though a para-unconformity is indicated on palaeontological and palynological grounds (KUMMEL et al. 1977). It is overlain conformably by the Tredian Formation in the Salt Range and by the Chak Jabbi Limestone in the Kalachitta Range. According to FATMI (1977), ammonoid fossils are abundant, the more significant ones being *Owenites, Anakashmirites, Meekoceras, Ophiceras, Glyptophiceras, Proptychites, Gyronites, Kymatites, Kingites* and *Ambites*. The brachiopods include *Lingula, Linoproductus, Spirigerella derbyi, Orthethetina, Enteletes, Orthotichia* and *Martinia* (KUMMEL & TEICHERT 1966). Forams, ostracods, crinoids and conodonts are also found in the Mianwali Formation (IQBAL et al. 1980); it has been assigned an Early Triassic (Scythian) age.

The **Tredian Formation** consists of a nonmarine sequence of thin- to thick-bedded, variegated, micaceous sandstone with ripple marks and slump structures interbedded with shale (the **Landa Member** of KUMMEL 1966) in the lower part which is 19 m – 29 m thick. The upper part of the Formation contains massive to thick-bedded sandstone (38 m – 59 m thick), interbedded with thin dolomite beds in the upper part (the **Khatkiara Member** of DANILCHIK et al. 1967). Formerly this Formation was known as "Kingriali sandstones" (GEE 1945), but later, GEE (in KUMMEL 1966) renamed it as the Tredian Formation. It is widely exposed in the Khisor Range and the Salt Range. The Tredian Formation contains spores, pollens and wood fragments; the significant ones are *Aratrisporites paenulatus, Calamospora, Cyciogranisporites arenosus, Falcisporites stabilis* and *Platysaccus queenslandi* (BALME 1970). This Formation overlies the Early Triassic Mianwali Formation conformably and grades into the overlying Kingriali Formation. The Tredian Formation is therefore regarded as of Middle Triassic age.

In the Kalachitta Range and in parts of Hazara District, the Mianwali Formation is overlain conformably by thin- to medium- bedded, grey, unfossiliferous sublithographic limestone, the **Chak Jabbi Limestone** (FATMI 1972), instead of the sandstone and shale of the Tredian Formation. The Chak Jabbi Limestone grades into the overlying Kingriali Formation. Its stratigraphic position is thus similar to the Tredian Formation. The Chak Jabbi Limestone is considered as of Middle Jurassic age.

The **Kingriali Formation** previously known as "Kingriali Dolomite" (GEE 1945), crops out in the Trans-Indus Range, Salt Range, Kalachitta, Kohat and in Southern Hazara. It contains thin- to thickbedded or massive, grey dolomite and dolomitic limestone with dolomitic shale and marl. It is 76 m - 106 m thick. Fossils are rare though some brachiopods, bivalves and crinoids have been reported (FATMI 1977). The lower contact of the Kingriali Formation is transitional with the Mianwali Formation or Chak Jabbi Formation and it has a disconformable contact with the overlying Jurassic Datta Limestone. It is therefore believed to be Late Triassic in age.

In the Mardan – Swat region of the Himalayan Thrust Belt, the Triassic sequence is mainly included in the Kashala and Nikanai Ghar Formations which form a part of the Alpurai Group. The **Kashala Formation** (DIPIETRO 1990) consists of calcareous-schist, garnet-actionolite schist and schistose marble with massive white to grey marble. The Formation is about 4,000 m thick and has a sharp contact with the underlying amphibolite of the Marghazar Formation. Marble beds near the middle of the Kashala Formation have yielded Upper Triassic (Carnian) conodonts – *Neogondolella polygnathiformis angusta* (POGUE et al. 1992).

South of the MMT, in the vicinity of Saidu (34° 45'N; 72° 22'E) and elsewhere in the Swat area and in thrust contact with mélanges of the Indus Suture Zone, there is a thick sequence of grey to dark-grey calcareous and pelitic schist which has been named **Saidu Schist** by KAZMI et al. (1986). Most of this schist is graphitic though chlorite schist is locally present. The metamorphic grade is upper greenschist to lower amphibolite. The Saidu Schist is included in the **Alpurai Group** of DIPIETRO (1990, 1991) and overlies the garnetiferous schist and marble of the Kashala Formation. About 30 km south of Saidu the Saidu Schist is replaced by the Nikanai Ghar Formation which overlies the Kashala Formation in this localityears Like the Nikanai Ghar Formation the Saidu Schist may also be Upper Triassic to Jurassic in age.

The **Nikanai Ghar Formation** (PALMER-ROSENBERG 1985, AHMAD et al. 1987) consists of white to grey, thick-bedded to massive crystalline marble and dolomitic marble with subordinate thin beds of calcareous schist, graphitic schist and quartzite. The marble beds contain poorly preserved fossils. Fossils collected by PALMER-ROSENBERG have been identified as "some type of colonial metazoans", Ordovician or younger in age, whereas the presence of a "questionable *palaeoniscoid* fish teeth" (Late Devonian to Jurassic) has been reported by POGUE et al. (1992). The Nikanai Ghar Formation is in fault contact with the underlying Kashala Formation and is tentatively assigned a Late Triassic to Jurassic age (POGUE et al. 1992).

Triassic rocks have been reported from the Tethyan Belt in Chitral (see Chapter 2.25). A thick sequence of massive, black dolomitic limestone exposed in the Mastuj Valley has been named **Zait Limestone** by TALENT et al. 1979. According to TAHIRKHELI (1982), this limestone has an extensive distribution and overlies early Devonian sandstone. Conodonts (*Anchignathodus typicalis, Anchignathodus isarcicus, Lonchodina triassica, L. inflata, Prionodian mulleri* and *Ozarkhdina* sp.) have been reported from this Formation and it is Triassic in age (TALENT et al. 1979, TAHIRKHELI 1982).

3.32 Jurassic

The Jurassic sedimentary rocks largely constitute a thick (820 m – 3,000 m) sequence of marine, pericratonic shelf deposits consisting of limestone, shale and sandstone with subordinate dolomite and ferruginous beds. They form a part of the platform cover in the entire Indus Basin (Fig. 3.1). In the Kirthar-Sulaiman region, the Jurassic outcrops are largely restricted to the anticlinal cores whereas, in the thrust belt, they form extensive thrust blocks or sheets.

The Jurassic rocks attain their maximum thickness in the Lower Indus Basin (3,000 m) where they mainly consist of marine limestone and shale (**Shirinab Formation**, Fig. 3.6 and its equivalent **Ferozabad Group, Takatu Formation** and **Mazar Drik Formation**). There is an apparently gradual transition from a dominant shale lithology of the underlying Triassic rocks to the thin-bedded intercalations of limestone and shale of the Jurassic (WILLIAMS 1959, Hunting Survey Corp. 1960). However, in the Upper Indus Basin (Kohat-Potwar area), the Jurassic sequence (**Datta Formation, Shinwari Formation, Samana Suk Formation** and the lower part of **Chichali Formation**) is much thinner (820 m) and consists mainly of arenaceous and argillaceous sediments of continental origin that grade upward into marine calcareous and argillaceous rocks (FATMI 1977). Here, the Jurassic unconformably overlies the Triassic Kingriali Formation, and there is an Upper Bathonian – Middle Callovian disconformity within the Jurassic sequence (Fig. 3.6).

In the Lower Indus Basin, the Jurassic sedimentary rocks underlie the Cretaceous with a marked unconformity (KAZMI 1981), whereas in the Upper part of the Basin no such unconformity is recognized (FATMI 1977).

In the Dir and northern Swat region of the Kohistan Island Arc terrain, a sequence of slate, limestone and quartzite, known as the **Kalam Group**, has yielded *Rhabdophyllia* sp., and is likely to be Middle Jurassic to Cretaceous in age.

In the Lower Indus Basin the **Shirinab Formation** (Hunting Survey Corp. 1960, FATMI 1977) is probably the earliest Jurassic exposed rock unit, ranging in thickness from about 1,500 m to 3,000 m. It consists of interbedded limestone and shale. According to FATMI (1977), it is transitional downwards and grades into the shaly Triassic Wulgai Formation. In fact the "Shirinab Formation" of Hunting Survey Corp. (1960) includes undifferentiated Jurassic, Triassic and even Permian rocks. The Shirinab Formation, as presently recognized is Early Jurassic in age and is exposed in the Kalat, Quetta, Zhob and Loralai Districts of Baluchistan. Equivalent rocks in the Khuzdar District have now been renamed **Ferozabad Group** (FATMI et al. 1986).

The Shirinab Formation has been subdivided into the Spingwar Member, Loralai Member and the Anjira Member (WILLIAMS 1959). The basal **Spingwar Member** includes a sequence of interbedded grey to black crystalline limestone about 600 m to 1,800 m thick, which is oolitic and shelly in places and contains calcareous shale with sandstone interbeds in its lower part. The type section is at Spingwar, 35 km northwest of Loralai (30° 32'N; 68° 9'E). According to WILLIAMS (1959) the Spingwar Member is considered to be Liassic in age on the basis of ammonites identified by the British Museum from near the type locality.

The **Loralai Limestone** overlies the Spingwar Member conformably and is a dominantly thin- to medium-bedded, dark grey to black, hard, crystalline limestone

(Fig. 3.7). The type section is at Zamarai Tangi (30° 32' 10"N; 68° 18' 40"E). The Loralai Limestone is overlain conformably by the Anjira Member in the area south of Kalat, whereas in the locality of the Zamarai Tangi it is overlain by Cretaceous rocks with an angular unconformity. It is considered Liassic in age owing to the fact that Toarcian to Bajocian fossils have been found in the overlying Anjira Member, whereas the underlying Spingwar contains Liassic ammonites.

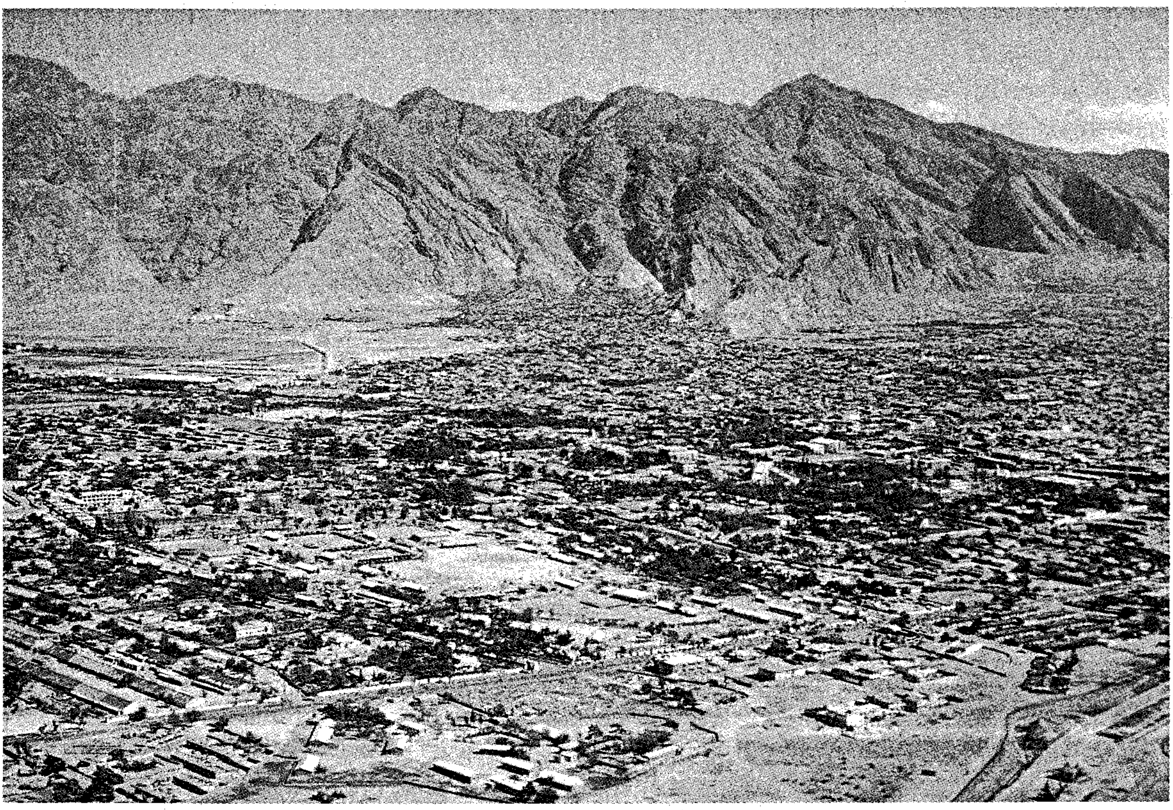


Fig. 3.7. Aerial view of Quetta to southeast to the Loralai Limestone Member of Lower Jurassic age of the Murdar Ghar (Photo: D. BANNERT).

The **Anjira Member** consists of dark-grey, thin, interbedded hard, locally porcellaneous to sub-lithographic limestone and softer argillaceous limestone with interbeds of splintery mudstone. Its thickness ranges from about 100 m to 400 m and its outcrops are apparently restricted to the Kalat-Khuzdar area. The type section is located about 12 km east of Anjira (28° 20' 18"N; 66° 28' 00"E). The ammonites collected from the Anjira Member range in age from Toarcian to Bajocian (WILLIAMS 1959). This unit is overlain disconformably by the Upper Jurassic to Lower Cretaceous Sembar Formation, or by the Lower Cretaceous Goru Formation. These latter two Formations are described in Chapter 3.33 (Cretaceous).

FATMI et al. (1986) have attempted to revise the stratigraphic nomenclature of the Jurassic sequence in the vicinity of Khuzdar and have introduced the name **Zidi Formation** (Ferozabad Group) which was previously designated by FATMI (1977) as the Shirinab Formation. The name "Zidi" was previously used by Hunting Survey Corp. (1960), but discarded by FATMI 1977 and the National Stratigraphic Committee.

Apparently the main difference between the Shirinab and the Ferozabad lithostratigraphic units is that the lower part of the Ferozabad Group contains a greater influx of clastic sediments and consists largely of grey to brown, micritic limestone, sandy limestone and sandstone with shale interbeds. More than 248 m of these sediments are exposed in the type section 17 km WNW of Khuzdar (27° 50'N; 66° 34'E). The upper sandstone contains poorly preserved molluscan shells, but it appears that no diagnostic fossils have yet been found in the lower unit. According to FATMI et al. (1986) the lower age limit of the Ferozabad Group is uncertain and doubtfully may be Triassic to Early Jurassic.

The lower unit of the Ferozabad Group is transitionally overlain by the middle unit, which consists of thick to massive, grey mottled, oolitic, coquinoid or micritic limestone with abundant bioturbated beds, and marly limestone intercalations. This unit is about 387 m thick in the Ferozabad section and has yielded abundant fragments of *Pecten weyla, Gervillia, Isocrines* and *Spiriferina* sp.

The middle unit grades into the upper unit, which is about 300 m thick and consists of brown to grey, thick-bedded limestone with marl and shale. *Spiriferina, Terebratula, Montlivaltia*, and Lower Toarcian to Lower Bajocian fossils like *Bouleiceras, Protogrammoceras, Dactylioceratids, Cenoceras, Hammotoceras, Phymatoceras, Phylsiogrammoceras, Graphoceras, Shaeroceras, Chandroceras*, and *Belemnopsis* have been identified (FATMI et al. 1986).

A para-conformity separates the Ferozabad Group and the overlying Sembar Formation. The Ferozabad Group (and its sub units) have been correlated with the Shirinab Formation.

In the Kalat, Quetta, Sibi and Loralai Districts, a massive to thick-bedded, dark- to light-grey or cream coloured, sub-lithographic to oolitic limestone, 750 m to 1,800 m thick, conformably and gradationally overlies the Shrinab Formation. At places the limestone is reefal or biohermal. It was named **Chiltan Limestone** by Hunting Survey Corp. (1960) and the name was adapted by FATMI (1977). Following WILLIAMS (1959), it has now been renamed **Takatu Limestone** (SHAH 1987). The type section is along Dara Manda south of Bostan (30° 22' 20"N; 67° 03' 39"E). Only poorly preserved or unidentifiable fossils have been found in this Formation and owing to its stratigraphic position between the Lower Jurassic Loralai Member of the Shirinab Formation and the overlying Callovian to Bathonian Mazar Drik Formation, the Takatu Limestone is considered as of Middle Jurassic age (FATMI 1977).

In the Sibi, Kalat and Khuzdar Districts, the Takatu Limestone is overlain conformably by the **Mazar Drik Formation** (ARKELL 1956), which consists mainly of interbedded grey limestone and dark shale. The type area is Mazar Drik in the Marri Hills where the Formation is about 30 m thick. A number of ammonites, including *Macrocephalites, Dolikephalites, Indocephalites, Pleurocephalites, Indosphonctes, Paralicidia, Bomburites, Choffatia, Bullatimorphites bullatus, Clydoniceras* have been found in this Formation (ARKELL 1956, FATMI 1969, 1977), and it is Callovian to Late Bathonian in age. The Mazar Drik Formation is overlain disconformably by the Sembar Formation.

In the Kohat Potwar region (Upper Indus Basin), the Jurassic sequence is relatively thinner than in the Lower Indus Basin, and limited in its extent. This sequence is divided into the Datta, Shinwari, and Samana Suk Formations.

The **Datta Formation** (DANILCHIK 1960), previously known as "Variegated Stage" (GEE 1945), contains the earliest Jurassic rocks in the region (Fig. 3.6) and consists largely of variegated sandstone, shale, siltstone and mudstone, at places interbedded with fire clay. The type section is in Datta Nala (33° 00'N; 71° 19'E) in the Surghar Range. Its thickness ranges from 150 m to 400 m, though northwards in Hazara, it is reduced to 10 m (FATMI 1977). The Datta Formation overlies the Kingriali Formation unconformably. In the Hazara area it rests unconformably on Precambrian, Palaeozoic or Triassic rocks. The Datta Formation is believed to be Early Jurassic inasmuch as it underlies the Toarcian Shinwari Formation.

The **Shinwari Formation** (FATMI 1977) has a transitional contact with the underlying Datta Formation and consists mainly of thin-bedded grey limestone, nodular marl, shale and sandstone. Current bedding and ripple marks are present. Its thickness ranges from 12 m in Kala Chitta to over 400 m in the Samana Range. It has a transitional contact with the overlying Samana Suk Formation. Fossils including *Bouleiceras, Terbratula, Spiriferina, Montivaltia, Pholadomya, Zeilleria, Pecten*, and *Lima* have been reported from the Shinwari Formation and it is believed to be Early Jurassic (Toarcian) to Middle Jurassic in age.

The **Samana Suk Formation** (DAVIES 1930) includes medium to thick-bedded, grey, oolitic and at places shelly or dolomitic limestone with interbedded marl and calcareous shale. It contains bivalves, gastropods, crinoids, brachiopods and ammonites: *Reineckeia ancepto, Choffatia* sp., *Obtusicostites* sp., *Hubertoceras* sp., and *Kinkeliniceras* sp., (FATMI 1977). The Formation is thus Middle Jurassic in age. Its thickness ranges from about 66 m in Chichali Pass to 366 m. It is overlain disconformably by the Chichali Formation.

In the Kohistan Island Arc terrain of Dir and Swat Districts, a sequence of slate, limestone and quartzite intruded by diorites have been described and named **Kalam Group** by MATSHUSHITA et al. (1965; see Chapter 2.253). The limestone, known as **Deshan Banda Limestone**, is thin-bedded, fine-textured and 35 m–45 m thick (TAHIRKHELI 1982). It has yielded *Rhabdophyllia* sp. (KARIG 1981) on the basis of which this limestone may be assigned to a Middle Jurassic to Cretaceous age. Thus at least the lower part of the Kalam Group (i.e. the **Baraul Banda Slate** and **Deshan Banda Limestone**) may be Jurassic in age.

In the Chitral region of the Tethyan Belt, a 3 km–4 km thick sequence of monotonous, soft, dark-grey shale with thin ash beds and subordinate fine sandstone is exposed west of Chitral and has been named **Chitral Slate** (DESIO 1959, 1966, 1975; CALKINS et al. 1981, TAHIRKHELI 1982, PUDSEY et al. 1985). According to PUDSEY, the slate is largely without bedding but it shows a complex structure. The sandstone may form as much as one third of the sequence and it is largely in the form of grey, fine-grained, thin- to medium-bedded quartzite though isolated fine-grained greywackes are also present sporadicallyyears Parallel lamination and graded bedding are common, slump structures are present and there is no bioturbation. No fossils have yet been found in the Chitral Slate and its base is not exposed.

In the Kunar River Valley, southwest of Chitral town (35° 52'N; 71° 48'E), the Chitral Slate forms an anticline the northwestern limb of which is overlain by the Cretaceous Kring Limestone. Its southeastern limb is overlain by the Koghazi Greenschist, which is conformably overlain by the unfossiliferous Gahirat Limestone (DESIO 1959, 1966, 1975; PUDSEY et al. 1985).

The **Koghozi Greenschist** comprises fine-grained, green chlorite-epidote-quartz schists interbedded with subordinate, thin, acidic layers with abundant quartz. Bedding is not very clear and the cleavage tends to anastomose (PUDSEY et al. 1985).

The **Gahirat Limestone** is grey, massive, and contains coarsely crystalline marble as much as 3 m thick. Southwest of Chitral, a zone of grey micaceous phyllite is seen in the middle of the limestone. According to PUDSEY et al. (1985) the phyllite is either infolded or introduced by faults.

Being unfossiliferous, there is no direct evidence for the age of the above sequence of the Chitral Slate, or of the Kaghozi Schist and the Gahirat Limestone. DESIO (1959, 1966, 1975) placed these Formations in the Triassic. CALKINS et al. (1981) have the Chitral Slate interpreted as of Cretaceous age. PUDSEY et al. (1985) have placed the Chitral Slate and Koghozi Greenschist in the Jurassic, and the Gahiral Limestone in the Cretaceous, though they concede that the Chitral Slate may range from Cretaceous down to Permian.

TAHIRKHELI (1982), on the other hand, has correlated the Chitral Slate with the Baltit Group, and the two units laterally merge without a tectonic or stratigraphic break. According to him, the Chitral Slate underlies the Lower Devonian sequence in the Mastuj Valley and across the border to Afghanistan. He has therefore proposed a Precambrian to Early Paleozoic age for the Chitral Slate.

3.33 Cretaceous

Cretaceous sedimentary rocks are exposed extensively in the Upper Indus Basin, the Foreland Thrust and Fold Belt, the Kohistan-Island Arc, the Tethyan Belt, and in the Chagai-Raskoh-volcanic and magmatic belt (see Chapter 2.21). At many localities the Cretaceous sequence contains volcanic rocks, obducted masses of mélanges and ophiolites and igneous intrusions.

In the Kirthar-Sulaiman region, except for local disconformities, there is a complete sequence of the Cretaceous ranging from Late Tithonian through Neocomian to Maestrichtian, constituting over 2,000 m of fossiliferous marine shale, carbonate and clastic sediments (Sembar and Goru Formations, Parh Limestone, Moghalkot, Fort Munro, Bibai and Moro Formations and Pab Sandstone). In the West Pakistan Foldbelt (see Chapter 2.23) of Baluchistan, the sequence consists largely of thrust blocks and sheets which include extensive sheets of volcanic rocks and obducted masses of mélanges and ophiolites.

In the Kohat-Potwar region of the Upper Indus Basin, the lower part of the sequence of Cretaceous age consists of marine sandstone and shale (Chichali and Lumshiwal Formations) with limestone (Kawagarh Formation) in the Upper Cretaceous. In this sequence there are disconformities; strata of Cenomanian, Turonian and Maestrichtian age are missing (Fig. 3.6).

In the northern areas of Pakistan, the Kohistan Island Arc rock complex (see Chapter 2.253) contains a thick Cretaceous sequence of volcanics and metasediments (Dir and Kalam Groups, Gwach, Purit and Drosh Formations, Shamran Volcanic Group, Rakaposhi Volcanic Complex, Burji, Katzarah and Bauma-Harel Formations). Farther northward the metamorphosed and highly tectonised and imbricated rock sequence of the Tethyan Belt includes a series of Cretaceous crystalline marble, phyllite, slate and shale (Gahirat Limestone, Krinj Limestone, Reshun Formation). A relatively thick sequence of volcanic and sedimentary rocks also crops out in the Chagai-Raskoh region of Baluchistan (Sinjrani Volcanic Group and Humai Formation).

The **Sembar Formation** (WILLIAMS 1959) is the lowermost unit of the Cretaceous sequence in the Kirthar-Sulaiman region, consisting of black shale interbedded with siltstone and nodular, argillaceous limestone. The shale and siltstone are commonly glauconitic. The Formation is 133 m thick in the type area (Sembar Pass 29° 55' 05; 68° 34' 48"E) and 262 m in the Moghal Kot section (31° 26'N; 70° 02'E). It has a gradational contact with the overlying Goru Formation though at places an unconformity has been reported by WILLIAMS (1959). The fossils most commonly found in the Sembar Formation are belemnites *Hibolithes pistilliformis, H.subfusiformis,* and *Duvalia* sp. It is mainly Neocomian in age. According to FATMI (1977) it may extend to the Late Jurassic.

The **Goru Formation** is composed of interbedded limestone, shale and siltstone. The lower part is more shaly and consists of very thin-bedded, light-coloured limestone interbedded with thin to irregularly bedded, calcareous, hard, splintery grey to olive-green shale. The upper part is largely thin-bedded, light-coloured, porcellaneous limestone with subordinate shale. It grades into the overlying Parh Limestone. At the type locality (Goru Village; 27° 50'N; 66° 54'E), the Formation is 536 m thick. Northwards in the Quetta area, the thickness is reduced to about 70 m whereas southwards in some of the wells drilled, 1,200 m to about 2,700 m of Goru sediments have been encountered.

The Goru Formation contains belemnites (*Hibolithes* spp.) and foraminifera (*Globigerinelloides algeriana, G. breggiensis, G. caseyi, Ticinella roberti, Gavelinella lorneiana, Rotalipora ticinensis, R. appennenica, R. brotzeni, R. reichli, Praeglobotruncana stephani* and *Planomalina buxtorfi* (FRITZ & KHAN 1967)). It is Cretaceous in age (Albian? to Cenomanian?; WILLIAMS 1959).

The **Parh Limestone** (BLANFORD 1879, VREDENBURG 1909 a, WILLIAMS 1959) is a very uniform, distinct and persistent rock formation and is exposed extensively in the Kirthar-Sulaiman region. It is thin-bedded, light-grey, white or cream coloured with a persistent pink, purple to maroon coloured band of interbeds of variegated shales and marls. The limestone is hard, lithographic to porcellaneous or argillaceous, platy to slabby with a characteristic conchoidal fracture. In the type area in the Parh Range (26° 54' 45"N; 76° 05' 45"E), the Parh Limestone is 268 m thick though elsewhere its thickness ranges from 300 m to 600 m. It has a conformable and gradational contact with the underlying Goru Formation and is overlain conformably by the Moghal Kot Formation. However, at many localities there is a disconformity at the top (WILLIAMS 1959; KAZMI 1955, 1979, 1988). East of Lasbela (26° 13'N; 66° 20'E), the Parh Limestone overlies the Cretaceous Porali agglomerate (DEJONG et al. 1979). In the Ziarat-Loralai area, the Parh Formation underlies a persistent laterite bed, whereas in the Kach-Kahan area, northwest of Ziarat (30° 25'N; 67° 44'E), the Parh Formation is interlayered with, and overlain by, basalts and tuffs of the Bibai Formation of Late Cretaceous age (KAZMI 1955, 1979, 1988).

The Parh Limestone contains many species of *Globotruncana* (KAZMI 1955, GIGON 1962) and is considered Upper Cretaceous (Barremian to Companian by KAZMI 1955, 1979; Senonian by WILLIAMS 1959).

The **Moghal Kot Formation** (WILLIAMS 1959, FATMI 1977) consists of grey calcareous shale and mudstone with intercalations of arkosic sandstone and grey argillaceous limestone. In the Sulaiman area the sandstone is well developed whereas in the Kirthar area the Formation is largely grey, silty, calcareous shale. In one of the oil wells (Dabbo Creek) near Karachi, basalts are present whereas near Kahan Village in the Ziarat area the formation locally contains a thick sequence of conglomerate with boulders and pebbles of basalt (Kahan Conglomerate Member of WILLIAMS 1959; Bibai Formation of KAZMI 1955, 1979, 1988). The thickness of the Formation ranges from about 150 m to 1,170 m. The type section is 2 km to 5 km west of Moghal Kot Post (31° 26'52"N; 70° 02'58"E).

In most areas the Moghal Kot Formation overlies the Parh Limestone unconformably, though in the type section and the Karachi region, according to FATMI (1977), the contact is apparently conformable. *Omphalocyclus* sp., *Orbitoides* sp., and *Siderolites* sp. have been reported from this Formation (WILLIAMS 1959, MARKS 1962), and it is assigned a Campanian to Early Maestrichtian age.

In the Ziarat area the sedimentary sequence equivalent to the Moghal Kot Formation has been named **Bibai Formation** (KAZMI 1955, 1979, 1984, 1988). The lower part of the Formation contains basaltic lava flows (at places, altered to laterite) and tuffs, locally interlayered with a thick sequence of a volcanic boulder conglomerate (Kahan Conglomerate Member of WILLIAMS 1959). The upper part consists of mudstones and ash beds with subordinate sandstones. This Formation is about 30 m to 610 m thick and lies unconformably on the eroded surface of the Parh Limestone; at places its basal part is interlayered with wedges of the Parh Limestone. The Bibai Formation grades into the overlying Dunghan Formation. According to KAZMI (1955, 1988), the interlayered Parh Limestone contains *Globotrunca lapparenti* and *G. linnei* which indicate a Campanian age of the lower part. In the upper part of the sequence the following fossils have been found by KAZMI (1955) near Kach: (Foraminifera): *Omphalocyclus macropora, Orbitoides* sp.; (Coelenterata): *Cyclolites* sp.; (Gastropoda): *Turritella, Acteonella* sp., *Ovula expansa* D'ARCHIAC & HEIME, *Nerinea quettensis,* NOETLING. *Crithium buddha* NOETLING, *Trochus lartetianus* LEYMERIE; *Volutillithes dubia* NOETLING, *Volutonomorpha* sp., *Polinices* (?) MONFORT, *Volutilithes* sp., *Planorbis* sp., *Conus* sp.; (Pelecypoda); *Vola quinqueangularis* NOETLING, *Nucula* sp., *Spondylus* sp., *Exogyra* aff. *pyrenaica;* (Echinodermata): *Hemipneustes* aff. *leymeri*; (Cephalopoda): *Scaphites, Turrilites, Baculites binodosus* NOETLING. This fauna indicates an Early to Middle Maestrichtian age for the upper part of the Bibai Formation (KAZMI 1955).

In the Sulaiman area, a dark-grey, hard, thick-bedded limestone, at places with marly and shaly interbeds, overlies the Mughal Kot Formation conformably and is known as the **Fort Munro Formation** (WILLIAMS 1959, FATMI 1977). In the Kirthar area, this limestone is grey, brown to cream coloured, thin-bedded in the upper part, and thick-bedded to massive and reefoid in the lower part. Its thickness ranges from 44 m to 248 m, and the type locality is in the western flank of Fort Munro anticline (29° 57'14"N; 70° 10'30"E). In the Sulaiman area it is overlain conformably and transitionally by the Pab Sandstone or by the Moro Formation. In the Quetta area it is overlain unconformably by the Dunghan Formation. The Fort Munro Formation contains *Omphalocyclus macropora, Orbitoides* spp., *Siderolites* sp. and *Actinosiphon punjabensis* and is considered Late Campanian to Early Maestrichtian in age (FATMI 1977).

The **Pab Sandstone** (VREDENBURG 1909 a, WILLIAMS 1959) is exposed in the Kirthar-Sulaiman region. It rests conformably on the Fort Munro Formation, but in some localities overlies the Parh Limestone unconformably (SHAH 1987). It consists mainly of white, cream or brown, thick-bedded to massive, cross-bedded, medium- to coarse-grained quartzose sandstone with intercalations of subordinate argillaceous limestone and shale. The type section is west of Wirahab Nai (25° 31'12"N; 67° 00'19"E) in the Pab Range where it is 490 m thick, although its thickness ranges from about 240 m (Mughal Kot) to 1,000 m (Pab Range). It is missing in parts of the Marri Bugti Hills and in the Quetta-Kalat area.

The Pab Sandstone is overlain conformably by the Moro Formation, but at places it is overlain unconformably by the Khadro, Rakhshani or Dungan Formations of Paleocene age (FATMI 1977). On the basis of Maestrichtian foraminifera the Pab Sandstone has been assigned a Late Cretaceous age (VREDENBURG 1908, WILLIAMS 1959, Hunting Survey Corp. 1960).

The **Moro Formation** (Hunting Survey Corp. 1960), which is exposed in the Kirthar-Sulaiman region, rests conformably and gradationally on the Pab Sandstone. Where the Pab Sandstone is not developed, the Moro Formation overlies the Fort Munro Formation conformably or rests disconformably on the Parh Limestone. It generally consists of a lower limestone unit, at places with volcanic conglomerate, a middle marly and shaly unit with subordinate sandstone, and an upper limestone unit. It is overlain conformably by the Dunghan Formation, although at places, the Khadro Formation rests on it disconformably (FATMI 1977). Foraminifera like *Globotruncana* aff. *G. linnei, Lituola* sp., *Omphalocyclus macropora, Orbitella media, Orbitoides* sp., and *Siderolites* sp. indicate that the Moro Formation is Maestrichtian in age. It is considered as a lateral facies of the Pab Sandstone, and is essentially the same as the Bibai Formation described earlier by KAZMI (1955).

In the Kohat-Potwar region the Cretaceous sequence includes the Chichali, Lumshiwal and Kawagarh Formations. The **Chichali Formation** (DANILCHIK 1961, GEE 1945) rests disconformably on the Samana Suk Formation and is mostly dark-green, glauconitic sandstone with grey, silty, glauconitic shale in the lower part. The type section is in Chichali Pass (33° 01'N; 70° 25'E). It crops out also in the Kalachitta and Hazara areas. Its thickness ranges from 12 m to 70 m. Cephalopods such as *Perisphinctes, Mayaites, Aspidoceras, Physodoceras, Katroliceras, Pachysphinctes, Belemnopsis gerardi, Hibolithes, Pulacosphinctoides, Hildoglochioceras, Provalanginites, Blanfordiceras, Spiticeras multiforme, Subthurmannia, Neocomites, Distoloceras, Olcostephanus* and *Lyticeras* have been found in this Formation and it has been assigned a Late Oxfordian to Neocomian age. According to FATMI (1977), the Chichali Formation is mainly of Late Jurassic age in the Hazara area.

The **Lumshiwal Formation** (GEE 1945, FATMI 1973) rests gradationally and conformably on the Chichali Formation. The type section is in the Lumshiwal Nala (32° 51'N; 71° 09'E). In the type locality and the Trans-Indus Ranges, this Formation is mostly grey, thick-bedded to massive, current-bedded feldspatic and ferruginous sandstone, but contains silty, or sandy, glauconitic shale toward the base. Northward and eastward, the Formation grades into a mostly marine sequence of sandstone, siltstone and shelly limestone. Its thickness ranges from 38 m to 194 m. Abundant moulds of brachiopods, bivalves, gastropods, ammonoids, belemnites and echinoids occur in this formation in the Samana Range (COX 1930 a). Ammonoids include *Ammonitoceras, Ailoceras, Douvilleiceras mammilatum, Oxytropidoceras* spp., *Desmoceras* sp., *Cleoniceras* sp., *Branchoceras* sp., and *Lemunoceras* sp. (SPATH 1930, FATMI 1968). Accordingly, the Formation has been assigned an Aptian to Early Albian age in the Kohat area, Neocomian to Middle Albian in Kalachitta and southern Hazara, and Tithonian to Middle Albian in northern Hazara (FATMI 1977).

The **Kawagarh Formation** (DAY in FATMI 1977, FATMI 1973) rests disconformably on the Lumshiwal Formation. In the type locality (Kawagarh Hills, 33° 45'30"N; 70° 28'30"E) and adjoining areas the Formation consists mainly of dark marl, calcareous shale and nodular, argillaceous limestone. In eastern Kohat, the lower part contains dolomitic limestone. Farther westward it consists of grey lithographic limestone (**Tsukail Tsuk Member**), and thin- to medium-bedded limestone with marl and shale (**Chalor Silli Member**). Its thickness ranges from 40 m to 200 m, but the Formation is missing in the Salt Range and Trans-Indus Range. Its upper contact with the Paleocene Hangu Formation is disconformable. It contains *Globotruncana lapparenti, G. fornicata, G. concavata carinata, G. elevata calcarata, Heterohelix reussi, H. globocarinate, H. globulosa, Pseudotextularia elegans, Rugoglobigerina rugosa* and *Globorotalites multisepta* (LATIF 1970 a, 1970 c). The age of the Kawagarh Formation is Late Cretaceous (Coniacian to Campanian).

The Kohistan Island Arc terrain contains a complex metasedimentary and metavolcanic sequence of Mesozoic age which has been described summarily by BARD et al. (1980) as follows:

- an upper detrital series (**Yasin Group** of IVANAC et al. 1956) Lower Cretaceous,
- a volcanic calc-alkaline series (**Utror Volcanics** of JAN et al. 1971), and
- a metasedimentary oceanic series (**Kalam Group** of MATSUSHITA et al. 1965).

This sequence is exposed south of the Main Karakorum Thrust (MKT) which denotes the suture between the Island Arc terrain (see Chapter 2.253) and the Eurasian Plate in the region extending from Dir and Chitral, through Gilgit, to Skardu and Ladakh. Many workers have studied and mapped this sequence in different segments of the arc, and several separate names have been proposed for the sequence. An extremely rugged terrain, a complicated schuppen structure and a varying degree of metamorphism have further complicated the definition and correlation of the tectonostratigraphy of the region. However, a summary of the Cretaceous stratigraphy of this area (from Dir and Chitral in the west to Skardu in the east) is given below.

The **Kalam Group** (MATSUSHITA et al. 1965, TAHIRKHELI 1979) crops out at several places between Dir (35° 12'N; 71° 53'E) and Drosh (35° 34'N; 71° 48'E) and extends northeastward. This Group, which is about 800 m thick, includes the **Karandoki Slate** at the base, overlain by the **Deshan Banda Limestone**, and **Shon Quartzite**. The Deshan Banda Limestone clasts in the overlying Utror Volcanics contain *Rhabdophyllia* sp. of corals, and the Kalam Group has been assigned a Middle Jurassic to Cretaceous age (TAHIRKHELI 1982). The Kalam Group is overlain by the **Dir Group** of rocks consisting of the **Baraul Banda Slate** with fossiliferous limestone interbeds (containing *Actinocyclina, Discocyclina* and *Nummulites atacicus*) which is in turn overlain by the **Utror Volcanics**. The Dir Group is faulted over the Kalam Group (TAHIRKHELI 1979). BARD et al. (1980) have described this sequence south of Drosh and south of the MMT as "Kalam type" metagreywacke series with shale, chert, marble and some oceanic gabbro and pillowed metabasalt, interlayered with "late-kinematic, heterogeneous quartzdiorite" and overlain by "calcalkaline lava flows (mainly andesite and dacite = **Utror Series**)". They state that these rocks underlie a thrust plate of "Drosh-Yasin red and green series with basal conglomerate, shale and fossiliferous Aptian-Albian limestone" containing Lower Cretaceous fossils which they refer to as the "detrital upper series". They have shown this sequence to continue eastward to Gilgit and Ladakh in the form of an arcuate belt.

A part of the above sequence between the Shandur Pass and Yasin has been referred to as the **Yasin Group** (IVANAC et al. 1956), which consists of lava, tuff and agglomerate containing lenses and beds of fossiliferous, massive to shaly limestone of Cretaceous age. This limestone yielded a Barremian to Aptian fauna including *Eugyra* cf., *E. neocomiensis* DEFROM, *Calamophylia* cf., *C. gracilis* BLAINY, *Thecosmilia* sp., *Isastrea* cf., *I. regularis* DEFROM, *Montastrea* sp., *Horiopleura haydeni* DOUB, *Horiopleura* cf., *H. haydeni* DOUB, *Horiopleura* cf., *H. lamberti* MUN-CHAL, *Nerinea* cf., *N. coquandi* D'ORB., and *Ptygmatis* n. sp., (BRUNNSCHWEILER in IVANAC et al. 1956).

Between Drosh and Shamran (36° 10'N; 73° 01'E) south of the MKT, PUDSEY et al. (1985) mapped and described the same sequence (Kalam-Utror-Yasin Groups), which they divided into three units as follows:

- **Drosh Formation** and **Shamran Volcanic Group**: Andesitic lava and red shale. The Drosh Formation overlies red shale of the Purit Formation and is 1.5 km thick.
- **Purit Formation**: Red shale, sandstone and conglomerate, 1 km thick, faulted against the Gawuch Formation, or resting unconformably on diorite.
- **Gawuch Formation**: Green phyllites and limestones, 2 km thick, intruded by diorite.

The **Shamran Volcanic Group** is exposed east of the Shandur Pass and is overlain by 500 m of well-bedded sediments, mostly red and green volcanic-lithic sandstone and shale, with micritic limestone which contains rare orbitolinas and rudists.

The geological map of PUDSEY et al. (1985) shows a fairly wide development and extent of the Drosh Formation and the Shamran Volcanic Group covering areas which had been earlier mapped and described as Greenstone Complex by IVANAC et al. (1956), which is discussed later.

The upper "metasedimentary, volcanic and detrital" sequence of the Kohistan Island Arc (BARD et al. 1980), lying immediately south of the MKT, may be traced eastward into the Skardu-Ladakh area. Here, a sequence of phyllite, slate, limestone and chlorite-epidote green-schist, several kilometers thick, is exposed south of the Indus River and has been named **Burji Formation** (DESIO 1978). The limestone contains Upper Cretaceous fossils.

The Burji Formation is interbedded with the **Deosai Volcanics** (WADIA 1937, TAHIRKHELI 1982), consisting mainly of andesite, rhyodacite and rhyolite. Northward and upward in the sequence, the Burji Formation has a faulted contact with the **Katzarah Formation** (DESIO 1963). This Formation consists of high-grade metasediments (amphibolite facies or higher) and crops out extensively in the Indus Valley and the lower

Shigar Valley in the Skardu region. The Katzarah Formation is about 1,500 m thick and includes hornfels, biotite schist, sillimanite-schist, gneiss and amphiobolite. DESIO (1964) has subdivided this Formation into **Tsordas Gneiss, Skoyo Gneiss, Askore Amphibolite** and **Katzarah Schist**. The Formation is intruded by pegmatite veins and dykes and sills of basic to acidic igneous rocks. The Katzarah Formation has been intruded by the **Ladakh Intrusives** (FRANK et al. 1977, IVANAC et al. 1956, TAHIRKHELI 1982).

The Katzarah Formation is overlain by the **Bauma-Harel Formation** (DESIO 1963) which largely consists of volcanoclastic metasediments that have been metamorphosed to chlorite-epidote greenschists. The greenschists are interbedded with slate, phyllite, minor carbonate layers and conglomerate that has clasts of shale, marble and greenschist (HANSON 1989). Northward, the outcrops are truncated by the MKT and covered by the thrust block of the Daltumbore Formation.

Earlier IVANAC et al. (1956) mapped the metavolcanic sequence of the Kohistan Island Arc Complex south of the MKT between Chitral and Gilgit and named it **Greenstone Complex**. They described it as an assemblage of lava, tuff, agglomerate, meta-gneisse, quartzite, limestone and calc-silicate rocks and, following WADIA (1935), assigned these rocks to the Triassic. As may be seen from the description of these volcanic rocks by other authors (MATSUSHITA et al. 1965; TAHIRKHELI 1979, 1982; BARD et al. 1980; PUDSEY et al. 1985; see Chapter 4.12), this rock sequence is now believed to be largely of Cretaceous age.

Following BARD et al. (1980), TAHIRKHELI (1982) has proposed a simplification of the stratigraphic nomenclature for the Late Mesozoic metavolcano-sedimentary sequence in the Kohistan Island Arc, and has used the name **Rakaposhi Volcanic Complex** for the Greenstone Complex of IVANAC et al. (1956). He apparently included the Shamran Volcanic Group of PUDSEY et al. (1985). According to TAHIRKHELI (1982), *Globotruncana* has been found in the Rakaposhi Volcanic Group in the Tissar section (35° 40'N; 75° 27'E) upstream of Shigar (35° 20'N; 75° 44'E), and *Thaminasteria matshushitai* near Shamran in Ghizar Valley, which indicate a Cretaceous age for this Group. TAHIRKHELI (1982) also has extended the Yasin Group from Skardu through Chalt, Ishkoman, Yasin to Chitral which implies that the Bauma-Harel Formation (DESIO 1963), the upper part of the Greenstone Complex of IVANAC et al. (1956), and the Purit and Drosh Formations (PUDSEY et al. 1985) may be included in the Yasin Group.

In the Chitral area, a thick platform-type Cretaceous carbonate sequence exposed in the Lutkho Valley, east of Shogor, has been named **Krinj Limestone** (DESIO 1959, TAHIRKHELI 1982). The limestone overlies the Chitral Slate and interfingers tectonically with the Reshun Formation (PASCOE 1959). The Krinj Limestone, which is about 2,5 km thick, is a sequence of grey, cream to white, micritic to finely recrystallised, massive to well-bedded limestone (PUDSEY et al. 1985). The limestone contains *Orbitolina discordia* and *Hippurites* sp. (DESIO 1959) and is of Late Cretaceous age.

Near Reshun, in the Mastuj Valley, a sequence of thick conglomerate overlain by maroon and red shales known as the **Reshun Formation** (HAYDEN 1915) forms an extensive outcrop. Both its upper and lower contacts are faulted; on one side it rests against the Chitral Slate and on the other against Devonian carbonate rocks (TAHIRKHELI 1982). This Formation also crops out in the Chitral and Shishi Valleys. It consists of marble, calcareous phyllite, red phyllite, conglomeratic phyllite and brown-weathering conglomerate (CALKINS et al. 1981). The conglomerate bed, which is 140 m to 1,500 m thick, has clasts of carbonate (44 %), volcanic rock (32 %), and quartzite (16 %). Because of its stratigraphic position and inclusion of orbitolina- and rudist-bearing limestone clasts, the Reshun Formation has been given a Late Cretaceous age (HAYDEN 1915, CALKINS 1981, TAHIRKHELI 1982, PUDSEY et al. 1985). DESIO (1959, 1966, 1975), however, has considered it as a Tertiary sequence.

Cretaceous volcanic-sedimentary rocks are extensively exposed also in the Chagai Volcanic Arc (see Chapter 2.21). The oldest rock sequence exposed in this region is the **Sinjrani Volcanic Group** (Hunting Survey Corp. 1960). This Group consists mainly of agglomerate, volcanic conglomerate, tuff and lava, with subordinate shale, sandstone and limestone. These rocks are 900 m to 1,200 m thick. Poorly preserved forminifera, corals (*Mesophyllum*) and algae have been found and the Group has been assigned to the Cretaceous.

The **Humai Formation** (Hunting Survey Corp. 1960) unconformably overlies the Sinjrani Volcanic Group south of Chagai Hills; elsewhere this contact is disconformable as indicated by a basal conglomerate. The lithology of this Formation is very variable and it consists of grey to purple shale, sandstone, siltstone, thin-bedded limestone, volcanic conglomerate and massive reefoid limestone with *Hippurites* sp., *H. loftusi, Lapeirousia* sp., *Monopleuridea, Lepidorbitoides socialis, Orbitella media, Orbitoides* sp., *Omphalocyclus* sp., and *Balculogypsinoides* sp. (FATMI 1977). The Humai Formation is of Maestrichtian age.

3.4 Cenozoic sedimentary rocks

The Cenozoic sedimentary sequence (Fig. 3.8) contains an exceptionally good record of the geodynamic processes during this Era which were responsible for the extinction and demise of the Tethys Ocean. This sequence records the effects of the Indo-Pakistan Plate collision with the Eurasian Plate, accompanied by the Himalayan orogeny, emplacement of ophiolite and mélange sequences, widespread volcanism and magmatism, and change from Palaeocene marine sequences to littoral and terrestrial molasse-type deposition during Neogene and Quaternary. It also records the evolution of vertebrate faunas. The present day configuration of the country was thus formed.

The Cenozoic sedimentary sequence consists of a largely marine Palaeogene sequence covered by dominantly terrestrial Neogene series of rock formations in the Indus Basin, and an entirely marine flysch-type sequence in the Baluchistan region (see Chapter 2.22). At most localities the Cenozoic sequence has an accumulated thickness of over 1,500 m (Fig. 3.1). A widespread hiatus marks the close of the Mesozoic Era and consequently, the Cenozoic-Mesozoic boundary is variable from place to place. In the Sulaiman and in the Baluchistan Ophiolite and Thrust Belt (West Pakistan Foldbelt, see Chapter 2.23), the Cenozoic-Mesozoic contact changes from an angular unconformity between Paleocene and older units (down to the Jurassic), to a disconformity and overlap in the Kohat-Potwar-Salt Range region (RAZA et al. 1989, GEE 1989). In the Lower Indus Basin, the contact between the Paleocene and the Cretaceous is disconformable (WILLIAMS 1959), though according to Hunting Survey Corp. (1960), it is transitional at places.

The various lithostratiographic units that comprise the Cenozoic sedimentary sequence are shown on Fig. 3.8.

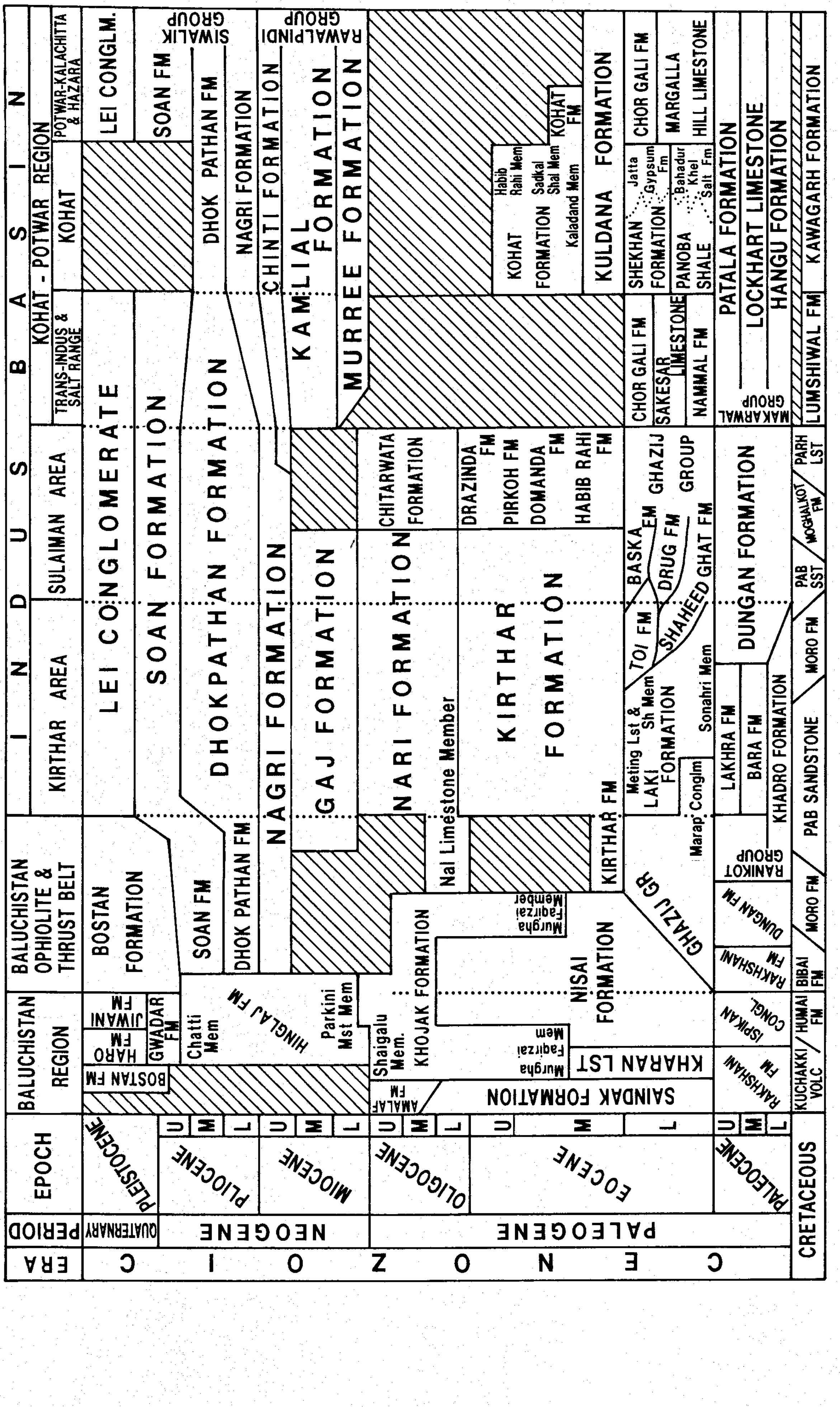


Fig. 3.8. Correlation of the Cenozoic Sequences.

3.41 Palaeogene

The Palaeogene sequence in Baluchistan rests conformably on the Humai Formation of Cretaceous age; in the Raskoh Range, it conformably rests on the Cretaceous Kuchakki Volcanic Group. The lower part of the sequence is called the **Rakhshani Formation** (Hunting Survey Corp. 1960, CHEEMA 1977), which consists of green to grey, medium to coarse-grained sandstone with lava flows, tuff and agglomerates. Subordinate grey to black argillaceous limestone beds in the lower part of the Formation contain foraminifera, bivalves, gastropods, corals and algae. The foraminifera include *Alveolina vredenburgi, Flosculina globosa, Miscellanea miscella*, and *Saudia labyrinthica*. The Rakhshani Formation is Paleocene in age.

The **Ispikan Conglomerate** (Hunting Survey Corp. 1960, CHEEMA et al. 1977) crops out only in the vicinity of Ispikan, 20 km northeast of Mand. It rests unconformably on Cretaceous marl. It contains unbedded and unsorted boulders and fragments of limestone (probably from Jurassic strata) and igneous rocks (including fragments from Sinjrani Volcanics). Blocks of the Eocene Nisai Formation rest on the Ispikan Conglomerate, which has been tentatively assigned a Paleocene age.

In the Kharan area, the Rakhshani Formation is conformably overlain by the **Kharan Formation** (Hunting Survey Corp. 1960, CHEEMA 1977; type section near Jalwar) which consists mainly of grey, thin- to thick-bedded, argillaceous, fossiliferous and reefoid limestone. It contains intercalations of thin, grey to brown, calcareous shale and fine- to medium-grained calcareous sandstone. Its thickness ranges from 90 m to 600 m. Some of the larger foraminifera found in the Formation are *Assilina granulosa, A. exponens, Flosculina globosa, Fasciolites oblonga, F. subpyrenaica, Discocyclina ranikotensis*, and *Orbitolites complanatus*. The age of the Formation is Early to Middle Eocene. The Kharan Formation is overlain conformably and transitionally by the Khojak Formation of Late Eocene to Oligocene age.

In the Chagai-Ras Koh area (see Chapter 2.21), the **Saindak Formation** (Hunting Survey Corp. 1960, CHEEMA 1977) rests conformably on the Rakhshani Formation. It consists of interbedded shale, sandstone, limestone and volcanic rocks. The shale is green to brown or maroon, sandy or calcareous with gypsum beds at places; the sandstone is green to brown, fine to coarse-grained, gritty and calcareous. The limestone is grey to brown and fossiliferous. The volcanic rocks include agglomerate and conglomerate containing fragments and boulders of lava flows. The thickness of the Formation ranges from about 60 m to 1,500 m. It contains foraminifera, gastropods, bivalves, corals and echinoderms. The fossils include *Assilina dandotica, A. exponens, Opertorbitolites douvillei,Fasciolites oblonga, Echinolampas nummulitica* and *Velates perversus*. This fauna suggests an Eocene age of the Saindak Formation.

The **Amalaf Formation** (Hunting Survey Corp. 1960; type section northwest of Amalaf in Chagai District) transitionally overlies the Saindak Formation. It consists mainly of volcanic ash and agglomerate with subordinate andesitic lava flows. The volcanic rocks are interlayered with shale and sandstone. This Formation is exposed in the western part of the Chagai District. No fossils have been yet reported from it, but the Formation has been tentatively assigned an Oligocene age (CHEEMA et al. 1977).

The **Nisai Formation** (Hunting Survey Corp. 1960, CHEEMA 1977; type section 12 km north of Nisai) is exposed along the eastern margin of the West Pakistan Foldbelt (see Chapter 2.23), and unconformably overlies various Mesozoic and Permian rocks. However, farther eastward, it rests conformably on the Ghazij Formation or it transitionally overlies the Ranikot Group. It is mainly comprised of grey to greyish-brown massive, brecciated, reefoid and shelly limestone. At places, the limestone is grey to black, well bedded and oolitic. The Formation contains subordinate amounts of marl, shale and conglomerate. The amount of these subordinate constituents varies from place to place. The shale is grey, calcareous, in places lateritic or carbonaceous; the sandstone is grey, brown, green or white, coarse, poorly sorted, cross-bedded, thick-bedded and protoquartzitic to orthoquartzitic. The conglomerate occurs at different horizons in different areas and comprises angular to rounded pebbles and boulders of limestone, sandstone, jasper and various igneous rocks. The thickness of the Formation ranges

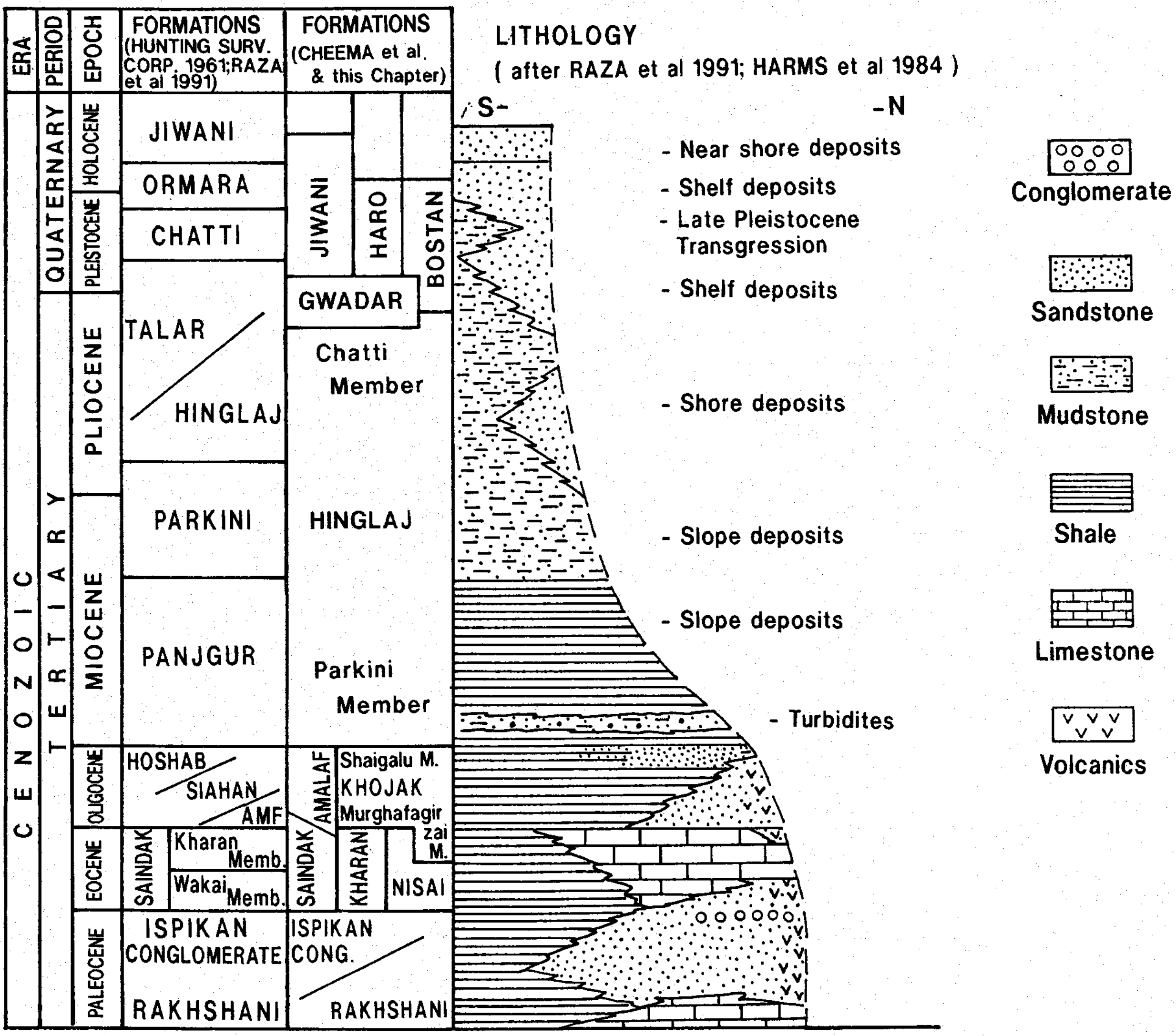


Fig. 3.9. Cenozoic sequences in the Baluchistan region.

from 30 m to 1,200 m. Fossils found in the Formation include *Assilina granulosa, A. subpapillata, Fasciolites globosa, F. oblonga, Discocyclina, Sowerbyi, Lockhartia conditi, L. newboldi, Nummulites atacicus, N. mammilla, Orbitolites complanatus, Pellatispira madaraszi, Fasciolites elliptica, Lepidocyclina dilatata, Nummulites intermedius* and *N. fichteli*. The age of the Nasai Formation is Eocene to Early Oligocene.

The Nisai Formation is conformably overlain by a thick sequence of flysch deposits ranging in age from Eocene to Pleistocene and these have been divided into several lithostratigraphic units by Hunting Survey Corp. (1960), HARMES et al. (1984) and RAZA et al. (1990). CHEEMA et al. (1977) have, however, lumped some of these units together to simplify the division of this sequence (Fig. 3.9). The latter classification has been followed in this paper.

The lower part of the flysch sequence consists of the **Khojak Formation** (VREDENBURG 1909 a, CHEEMA 1977; the type locality is Nauroz about 30 km northeast of Kharan). It consists of shale, sandstone and siltstone with subordinate limestone and conglomerate. The lower part consists mainly of grey, green to brown, calcareous and arenaceous shale, named the **Murgha Faqirzai Member** (Hunting Survey Corp. 1960, CHEEMA 1977, IQBAL 1980). The upper part is largely grey, green to brown, cross-bedded calcareous, micaceous sandstone with subordinate conglomerate. This upper arenaceous part has been named **Shaigalu Member** (CHEEMA 1977; the type locality is at Shaigalu 50 km southwest of Fort Sandeman). The thickness of the Khojak Formation ranges from 900 m to over 1,500 m. Fossils found in the Formation generally include *Lepidocyclina dilatata, Nummulites fischteli, N. intermedius, N. vascus* etc. (EAMES 1939, Hunting Survey Corp. 1960) which indicate an Oligocene age. However, from some localities a Paleocene to Eocene assemblage is known including *Assilina granulosa, Nummulites atacicus, N. globulus, N.* cf. *irregularis, Discocyclina ranikoti*, or Oligocene to Early Miocene gastropods like *Telescopium charpentieri* and *Tympanotonous margaritaceous* and *Ostrea gryphoides* have been found (Hunting Survey Corp. 1960). The age of the main part of the Khojak Formation is thus Oligocene and it may range from Eocene to Early Miocene.

3.42 The Palaeogene sequence in the West Pakistan Foldbelt

In the West Pakistan Foldbelt (see Chapters 2.23, 5.23), the Palaeogene rocks are mostly faulted and folded blocks and thrust slices of the Paleocene Dungan and Khadro Formations overlain or flanked by the Ghazij Group and Nisai Formation of Eocene age and the Khojak Formation of Oligocene age. The Khojak Formation has been described earlier, whereas the other formations are described in the following paragraphs (Fig. 3.8). The sequences are discussed for the Kirthar area, for the Sulaiman area, and for the Kohat-Potwar area.

In the Kirthar area of the Indus Basin, the Paleocene succession consists of the **Ranikot Group** (BLANFORD 1876, 1879; VREDENBURG 1909 b). This Group has a basal marine sequence of sandstone and shale with interbeds of limestone and basaltic lava flows (Khadro Formation), a middle fluviatile to paralic sequence of sandstone and shale with coal and carbonaceous beds (Bara Formation), and an upper sequence consisting of marine limestone and some estuarine sandstone and shale (Lakhra Formation).

The **Khadro Formation** (WILLIAMS 1959), which is widely distributed in the Kirthar and adjacent region, lies unconformably on the Late Cretaceous Pab Sandstone and the Moro Formation. The type locality is Bara Nai (26° 07'06"N; 67° 53'12"E) in the Lakhi Range. At the type locality, the basal part of the Formation consists of limestone containing oysters and reptile bones. This is followed by a series of olive, brown, green to grey, soft, ferruginous, medium-grained fossiliferous sandstone and olive, grey to brown gypsiferous shale with interbeds of fossiliferous limestone. A number of basaltic lava flows are also present. The thickness of the Formation is 67 m in the type section; in the Rakni Nala, Sulaiman area, it is 170 m thick, whereas in test holes at Lakhra and Dabbo Creek, thicknesses of 140 m and 180 m were penetrated (CHEEMA et al. 1977). Fossils described from the Khadro Formation include *Corbula (Vericorbula) harpa, Leionucula rakhiensis, Venericardia vredenburgi, Tibia (Tibiochilus) rakhiensis* (EAMES 1952); *Cardita beaumounti* (BLANFORD 1878); *Globigerina pseudobulloides* and *G. triloculinoides* (NAGAPPA 1959); *Howecythereis multispinosa, H. micromma* and *Paracypris rectoventra* (SOHN 1959). The Formation has thus been considered to be Early Paleocene in age.

The **Bara Formation** (CHEEMA et al. 1977) conformably overlies the Khadro Formation and is widely distributed in the Kirthar- and adjacent areas. The type section is in Bara Nai (26° 07'06"N; 67° 53'12"E), in the Lakhi Range. The Formation consists of interbedded sandstone and shale. The sandstone is fine- to coarse-grained, calcareous, ferruginous and at places glauconitic, ripple-marked and cross-bedded. Beds range in thickness from a few centimeters to over 3 m. The shale is soft, earthy, gypsiferous and commonly carbonaceous.

Oyster shells, some reptile remains and abundant leaf impressions have been found. *Ostraea talpur* has been reported from the base (VREDENBURG 1928). The Formation has been given a Middle Paleocene age (Thanetian).

The **Lakhra Formation** (CHEEMA et al. 1977) overlies the Bara Formation and crops out in the Kirthar- and adjacent areas. The type section is in the southern part of the Lakhra anticline. It consists mostly of grey, thin- to thick-bedded, nodular, sandy and in places argillaceous, fossiliferous limestone, with interbeds of sandstone and shale in the upper part. Its thickness ranges from 50 m to about 242 m. The Formation contains a rich assemblage of foraminifera (DAVIES 1927, NUTTAL 1931), corals (DUNCAN 1880), molluscs (VREDENBURG 1909 b, 1928) and echinoids (DUNCAN & SLADEN 1882). The more significant larger foraminifera include *Miscellanea miscella, M.stampi, Lockhartia haimei, Lepidocyclina punjabensis, Discocyclina ranikotensis, Nummulites nutalli, N. thalicus, N. globulus, N. sindensis, Assilina ranikoti.* The Lakhra Formation is Late Paleocene in age.

The **Laki Formation** (NOETLING 1903, Hunting Survey Corp. 1960) overlies the Ranikot Group unconformably and is exposed mainly in the southern Kirthar Range and in the southern Sulaiman Range. A section 5 km south-southwest of Meting (25° 12'N; 68° 10'E) and near Mari Nai (26° 06'N; 67° 51'E), in the northern Lakhi Range, are the type localities. Its basal part, the **Sonari Member** (Hunting Survey Corp. 1960) contains lateritic clay, shale pockets of limonite and ochre, coal beds, sandstone and locally-developed yellow, areanaceous limestone.

The Sonari Member is overlain by the **Meting Limestone and Shale Member** (VREDENBURG 1906) which consists of thin-bedded, creamy white, fossiliferous, nodular limestone followed by a sequence of interbedded limestone and shale with subordinate sandstone. The Formation contains gastropods, bivalves, echinoids, foraminifera and algae (NOETLING 1905, NUTTALL 1925, DAVIES 1926 a, HAQUE 1962 a, Hunting Survey Corp. 1960, IQBAL 1973). The more significant foraminifera include *Assilina granulosa, A. pustulosa, Lockhartia hunti* var. *pustulosa, Flosculina globosa, Opertorbitolites douvillei, Fasciolites oblonga, Linderina brugesi* and *Dictyoconoides vredenburgi*. The age of the Laki Formation is Early Eocene (Ypresian).

The **Kirthar Formation** (BLANFORD 1876, NOETLING 1903, OLDHAM 1890, CHEEMA et al. 1977) overlies the Laki Formation conformably in the Kirthar area. It is distributed widely and covers also the Sulaiman area and parts of Waziristan. In these areas it overlies the Ghazij Group conformably. The type area is in the Kirthar Range (Gaj River section, 26° 56'10"N; 67° 09'06"E). The Formation is mainly fossiliferous limestone interbedded with subordinate shale and marl. The limestone is thick-bedded to massive, nodular in some areas, grey to white in colour and locally contains algal and corraline structures. In some localities, the upper half of the Formation is massive, cliff-forming limestone. The shale is olive, orange, yellow or grey, soft, earthy and calcareous. The thickness of the Formation ranges from 15 m to 30 m in the western Kirthar Range to 1,270 m in the Gaj River type section (CHEEMA et al. 1977).

The Formation contains abundant foraminifera, gastropods, bivalves, echinoids and vertebrate remains (OLDHAM 1890; VREDENBURG 1906, 1909 a; PILGRIM 1940; EAMES 1952; Hunting Survey Corp. 1960). The age of the Kirthar Formation is Middle Eocene to Early Oligocene.

The **Nari Formation** (BLANFORD 1876, WILLIAMS 1959) is exposed extensively in the Kirthar-Sulaiman region, whereas scattered outcrops are found in tectonized thrust blocks in the Baluchistan Ophiolite and Thrust Belt. In the Kirthar area it conformably overlies the Kirthar Formation except in the Hyderabad anticlinorium where it oversteps and unconformably overlies the Laki and Kirthar Formations. The type section is in the Gaj River Gorge (26° 56'12"N; 67° 10'10"E) in the Kirthar Range.

The upper part of the Nari Formation is mostly brown, fine- to coarse-grained sandstone (locally conglomeratic) with interbeds of shale. The lower part consists of interbedded grey to brown, fossiliferous sandy limestone, calcareous sandstone and shale. At many localities, the lower part of the Formation is a grey to brown, shelly, nodular, thick-bedded to massive limestone which has been named the **Nal Member** (Hunting Survey Corp. 1960). The thickness of the Nari Formation ranges from 1,045 m to 1,820 m in the Kirthar area. It contains a rich fauna including echinoids, molluscs, corals, foraminifera and algae (DUNCAN et al. 1884; VREDENBURG 1906; NUTTALL 1925-1926; Hunting Survey Corp. 1960; PASCOE 1963; KHAN 1968, IQBAL 1969 b). Some of the significant larger foraminifera include *Nummulites intermedius, N. vascus, N. fichteli, N. clipens* and *Lepidocyclina dilatata*. The age of the Nari Formation is Oligocene to Early Miocene (Rupelian to Early Aquitanian; LATIF 1964, KHAN 1968).

In the Sulaiman area the **Dungan Formation** (OLDHAM 1890, WILLIAMS 1959, CHEEMA et al. 1977, KAZMI 1988) forms the basal part of the Palaeogene sequence and oversteps most of the Cretaceous rock units (Parh Limestone, Moghal Kot Formation, Pab Sandstone). It crops out extensively in the northern part of the Kirthar Range, and the whole of the Sulaiman Range. The type section is in the Mehrab Tangi (30° 08'38"N; 67° 59'33"E), 8 km northeast of Harnai. The Formation consists largely of thick- to medium-bedded to massive nodular limestone with subordinate marl, shale and sandstone. Its thickness varies from about 100 m to over 600 m. It contains a rich fossil assemblage of foraminifera, gastropods, bivalves and algae (DAVIES 1941, Hunting Survey Corp. 1960, LATIF 1964, IQBAL 1969 a, KAZMI 1988). Some of the more common and significant larger foraminifera found in the Formation are *Miscellanea miscella, M. stampi, Lockhartia tipperi, Kathina selveri, Operculina, Discocyclina, Nummulites nuttalli, N. thalicus, N. sindensis, Assilina dandotica* and *Fasciolites*. The age of the Dungan Formation is Paleocene to Early Eocene.

The **Ghazij Group** (OLDHAM 1890, WILLIAMS 1959, SHAH 1990) conformably overlies the Dungan Formation and crops out extensively in the Sulaiman Range and the northern part of the Kirthar Range. The type section is at Spintangi (29° 57'N; 68° 05'E). The Group dominantly consists of shale, interbedded with layers and lenses of claystone, mudstone, sandstone, limestone, conglomerate and alabaster (KAZMI 1962); it contains deposits of coal which are being mined. Its thickness ranges from about 160 m at Roara Nai (Kirthar Range), 590 m at the type section (Spintangi) to about 1,300 m at Moghal Kot. The Ghazij Group contains foraminifera, gastropods, bivalves, echinoids, algae and plant remains (EAMES 1952, Hunting Survey Corp. 1960, LATIF 1964, IQBAL 1969 a). The foraminifera include *Flosculina globosa, Assilina sublaminosa, Lockhartia hunti, Coskinolina balsilliei* and *Dictyoconus indicus*. The Ghazij Group is Early Eocene in age, and has been further subdivided into the following lithostratigraphic units (Fig. 3.8):

The **Marap Conglomerate** (Hunting Survey Corp. 1960) crops out in the Kalat Plateau area and forms the basal part of the Ghazij Group. At places, the conglomerate constitutes the entire Group. It consists of well rounded and poorly sorted pebbles and boulders of limestone, shale and sandstone derived from the underlying formations including the Jurassic rocks. The conglomerate is interbedded with subordinate shale, sandstone and, less-commonly, limestone. The Marap Valley is the type locality where it is about 910 m thick.

The **Shaheed Ghat Formation** (SHAH 1987, 1990) is exposed in the Quetta-Moghul Kot area. It overlies the Dungan Formation and forms the lower part of the Gazij Group. The type section is at Shaheed Ghat (34° 24'N; 70° 27'E), 5 km southwest of Zinda Pir. The Formation consists of grey to olive green, laminated shale with marl. At places the shale contains layers with nummulites, gastropods and lamellibranchs. The thickness of the Formation ranges from about 340 m at Moghul Kot to over 680 m at Shaheed Ghat. The Shaheed Ghat Formation is Early Eocene in age.

The **Drug Formation** (SHAH 1987, 1990) overlies the Shaheed Ghat Formation conformably and crops out in the Sulaiman Range and adjacent areas. The type section is at Drug Tangi (30° 49'15"N; 70° 12'30"E), 3 km northeast of Drug Village. The Formation consists largely of limestone, interbedded with subordinate shale. The limestone is orange, pale-olive, grey-green to creamish-white in colour. It is thin-bedded, hard, pebbly and nodular, crystalline, argillaceous, and commonly has marly partings. At places it is bioclastic and of calcirudite type. The lower part of the Formation is mostly shale which is greenish-grey to dark grey, calcareous, at places pyritic or with ferruginuous concretions, and interbedded with minor limestone. The thickness of the Formation ranges from 40 m at Drug Tangi to 340 m in the Zinda Pir area. The Drug Formation is Early Eocene in age.

The **Toi Formation** (SHAH 1987, 1990) overlies the Drug Formation conformably, and, where the Drug Formation is missing, it overlies the Shaheed Ghat Formation conformably (Fig. 3.8). It crops out extensively in the Sulaiman Range; the type section is in the Toi Nala (31° 05'N; 70° 11'E). It consists mainly of interbedded sandstone and mudstone, siltstone, shale and conglomerate with locally-developed coal beds. The sandstone is coarse-grained, pebbly, poorly-sorted and cross-bedded, at places containing freshwater bivalves, gastropods and plant remains. The mudstone and siltstone are brown to reddish-brown, soft, blackish and calcareous. Locally the Formation contains thin beds of fossiliferous limestone interbedded with mudstone and shale. The maximum thickness of the Formation is about 1,196 m in the Moghal Kot section. The Toi Formation is Early Eocene in age.

The **Baska Formation** (HEMPHIL et al. 1973) overlies conformably the Toi Formation and forms the upper part of Ghazij Group in the Sulaiman Range. The type locality is 2 km east-northeast of Baska Village (31° 29'N; 70° 08'E). The Formation consists of green to grey shale and claystone, interbedded with alabaster, gypsiferous limestone and marl. The alabaster beds range in thickness from a few centimeters to 10 m. At places, the shale is interbedded with thin limestone beds. The thickness of the Formation ranges from about 160 m in the north to about 820 m in the southern part of the Sulaiman Range. It contains foraminifera, bivalves and gastropods. The larger foraminifera include *Lockhartia hunti* and *Dictyoconoides vredenburgi*. The Baska Formation is Early Eocene in age.

The **Kirthar Formation** conformably overlies the Ghazij Group in most of the Sulaiman Range; it has been described earlier. However, in the Sulaiman Range and Kohat area, the Ghazij Group (and its equivalent Formations) are conformably overlain in ascending order by the following Formations which were previously considered as sub-units of the Kirthar Formation (CHEEMA et al. 1977, SHAH 1987):

The **Habib Rahi Formation** (TAINISH 1959, MEISSNER et al. 1968) overlies the Baska Formation conformably and transitionally and the type section is proposed north of Zampost, along the Ft. Sandeman – Dera Ismael Khan road. The Formation is largely greyish-brown, thin- to thick-bedded or massive, hard, argillaceous, fossiliferous limestone, with nodules and cherty beds (Fig. 3.10). Its thickness ranges from 15 m to 150 m. The Habib Rahi Formation is Middle Eocene in age.

The **Domanda Formation** (HEMPHILL et al. 1973) overlies the Habib Rahi Formation, conformably and transitionally, and its type locality is west of Domanda (31° 35'30"N; 70° 12'E). It consists mainly of dark brown to greenish grey claystone with intercalations of limestone at some places, and with subordinate grey to brown, fine- to medium-grained thick-bedded to massive calcareous sandstone in the upper part. Its thickness ranges from about 130 m to 330 m. It contains foraminifera, gastropods, bivalves, echinoids and rare vertebrate fossils. The foraminifera include *Nummulites beaumonti, N. subbeaumonti, Alveolina elliptica*, and *Dictyoconoides cooki*. The age of the Domanda Formation is Middle Eocene.

The **Pirkoh Formation** (HEMPHILL et al. 1973) conformably overlies the Domanda Formation and the Pirkoh anticline is its type locality. It consists of brown, grey to white, thin-bedded limestone with subordinate beds of soft argillaceous limestone, and dark-grey calcareous claystone. Its thickness ranges from 10 m to 175 m. It is highly fossiliferous and contains foraminifera, gastropods, bivalves and echinoids of Middle Eocene age.

The **Drazinda Formation** (HEMPHILL et al. 1973) overlies the Pirkoh Formation conformably and transitionally; the type locality is northeast of Drazinda (31° 46'N; 70° 09'E). It consists of brown to grey clay with subordinate fossiliferous marls and brown fossiliferous limestone interbeds. At places it is interbedded with grey, calcareous sandstone in the middle part. In the northern Sulaiman Range it contains celestite nodules. Its thickness ranges from 15 m to 500 m. It contains a rich fauna of foraminifera, bivalves, bryozoans and echinoids. Its age is Middle Eocene.

The Kirthar Formation and the Drazinda Formation of Eocene age are unconformably overlain by the **Nari Formation** of Oligocene age in the Sulaiman Range, which has been described earlier. In this region the Nari Formation is as much as 600 m thick.

In the Sulaiman Range the Oligocene sequence which was previously referred to as Nari Formation, has now been renamed as the **Chitarwata Formation** (HEMPHILL 1973, EAMES 1952, SHAH 1987). The type section is at Chitarwata Pass (31° 03'N; 70° 14'E). The Formation consists of red, grey and green claystone, siltstone and sandstone. The lower part is largely sandstone which is ripple-marked and cross-bedded at places. At some localities, hard ferruginous sandstone and conglomerate are present near the top of the Formation. The thickness of the Formation ranges from 150 m to 300 m. It contains freshwater gastropods and bivalves (IQBAL 1969) and the plant species *Croftiella escheri* on the basis of which the age of the Formation has been determined as Oligocene.

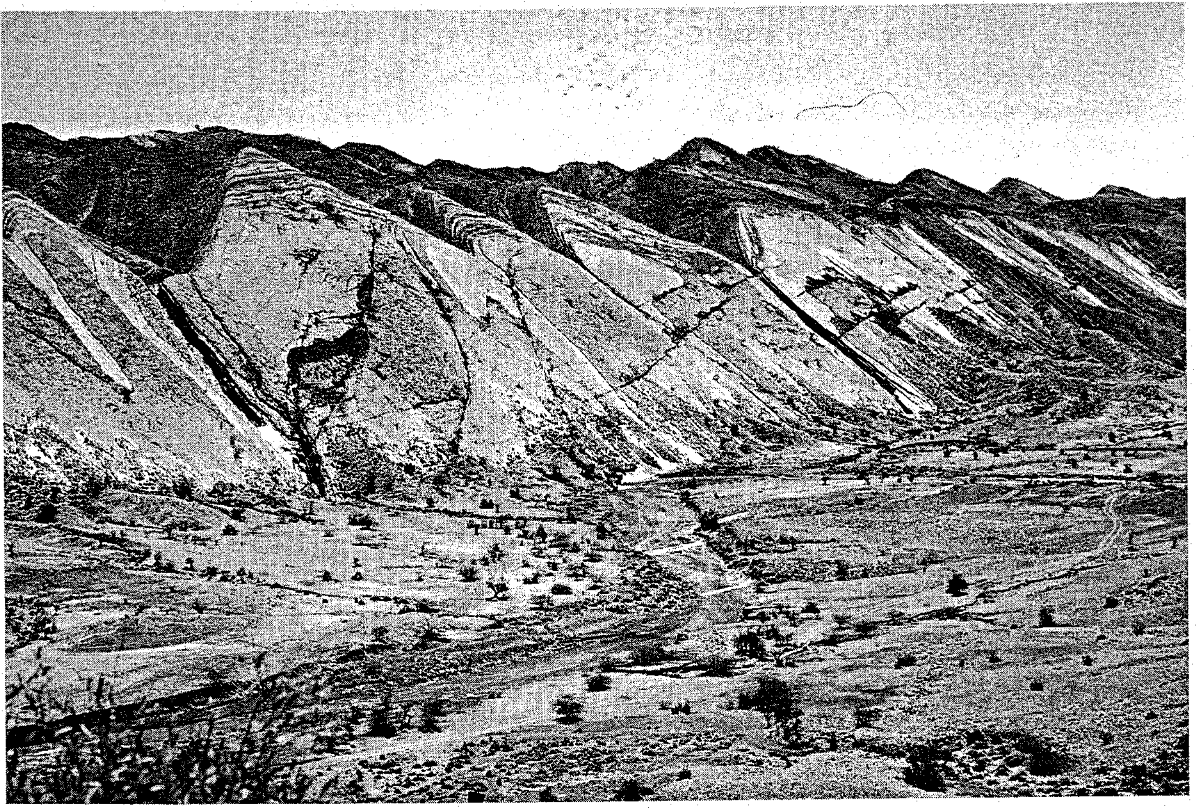


Fig. 3.10. Habib Rahi Formation dipping west. West of Dera Ismael Khan, Sramorga Range southeast of Domanda (Photo: D. BANNERT).

In the **Kohat-Potwar area** the lower part of the Palaeogene sequence, comprising the Paleocene **Makarwal Group** of GEE (1989), has been deposited over the eroded surfaces of rocks ranging in age from Cretaceous to Cambrian (Fig. 3.8). It extends rather uniformly over this region and includes a basal sandstone unit of terrestrial origin (Hangu Formation), a middle marine limestone unit (Lockhart Limestone), and an upper shale unit with subordinate sandstone and limestone (Patala Formation) which was deposited in the offshore region and in a back-barrier basin.

The **Hangu Formation** (DAVIES 1930, FATMI 1973) unconformably overlies various formations of Paleozoic to Mesozoic age. The type locality is south of Fort Lockhart (33° 33'40"N; 71° 03'E) in the Samana Range. It consists largely of grey to brown, fine- to coarse-grained, silty and ferruginous sandstone which grades upward into fossiliferous shale and calcareous sandstone. At places, the Formation is intercalated with grey argillaceous limestone and carbonaceous shale. In the Makerwal and Hangu areas, it contains coal beds in the lower part. Its thickness ranges from about 15 m in Hazara to 150 m at Kohat Pass. The Formation contains molluscs, corals and foraminifera (GREGORY 1930, COX 1930 b, DAVIES et al. 1937, IQBAL 1972, SMOUT & HAQUE 1956). Some of the important foraminifera include *Miscellania miscella, Lockhartia haimei, L. conditi, Lepidocyclina punjabensis, Operculina* cf. *canalifera* and *Daviesina longhami.* The Hangu Formation is Early Paleocene in age.

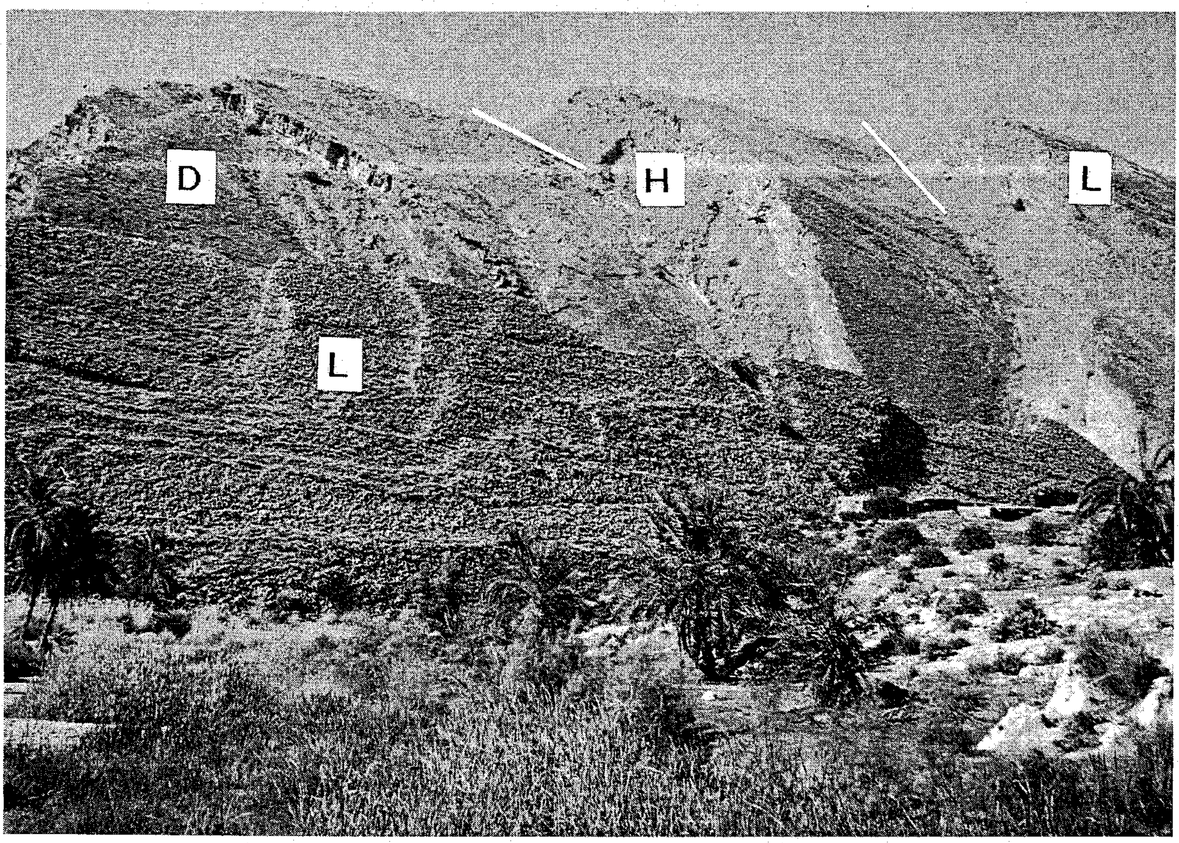


Fig. 3.11. Hangu Formation (H) and Lockhart Limestone (L), underlain by the Datta Formation. Nammal Gorge, Potwar Plateau (Photo: D. BANNERT).

The **Lockhart Limestone** (DAVIES 1930, FATMI 1973) conformably overlies the Hangu Formation (Fig. 3.11). Its type section is exposed near Fort Lockhart (33° 26'N; 70° 30'E). It consists of grey, medium- to thick-bedded and massive limestone, which is rubbly and brecciated at places. In Hazara and Kalachitta it contains subordinate intercalations of grey marl and shale. Its thickness ranges from about 30 m to 240 m. It contains foraminifera, corals, molluscs, echinoids and algae (COX 1931, DAVIES & PINFOLD 1937, DAVIES 1943, EAMES 1952, HAQUE 1956, IQBAL 1969 a, LATIF 1970 c). Some of the important larger foraminifera comprise *Operculina subsalsa, O. juvani, Miscellanea miscella, M. stampi, Lockhartia haimei, L. newboldi, Lepidocyclina punjabensis, Discocyclina ranikotensis, Alveolina globosa, A. vredenburgi, Assilina dandotica, Nummulites nuttali, N. thalicus, N. sindensis* and *N. globulus*. The echinoderms include *Conoclypeus, Eurhodia morrisi, Hemiaster elongatus, Pleisolampas ovalis* and *P. placenta*. The age of the Lockhart Limestone is Paleocene.

The **Patala Formation** (DAVIES & PINFOLD 1937) overlies the Lockhart Limestone conformably and its type section is in the Patala Nala (32° 40'N; 71° 49'E) in the western Salt Range. It consists largely of shale with subordinate marl, limestone and sandstone. Marcasite nodules are found in the shale. The sandstone is in the upper part. The Formation also contains coal (WARWICH et al. 1988, 1990), and its thickness ranges from 27 m to over 200 m. It contains abundant foraminifera, molluscs and ostracods (DAVIES & PINFOLD 1937, EAMES 1952, SMOUT & HAQUE 1956, LATIF 1970). The larger foraminifera include *Lockhartia conditi, Nummulites globosa, Operculina canalifera, O. patalensis, Discocyclina ranikotensis, Assilina dandotica, Daviesina intermedia* and *Kathina hammalensis*. The age of the Patala Formation is Late Paleocene.

The Patala Formation is overlain conformably by different sequences of Eocene age in different parts of its distribution area.

In the Trans-Indus Range and the Salt Range, the Eocene succession consists of the Nammal Formation, the Sakesar Limestone and the Chor Gali Formation. The **Nammal Formation** (GEE 1935, FATMI 1973) with type section in Nammal Gorge (32° 40'N; 71° 07'E), consists of shale, marl and argillaceous limestone. The lower part tends to be more shaly and marly, the upper part is dominantly limestone. Its thickness ranges from 35 m to over 130 m. The Formation contains molluscs and foraminifera (COX 1931, HAQUE 1956, KHAN in FATMI 1973). Some of the important foraminifera are: *Nummulites atacicus, N. subatacicus, N. mamilla, N. Lahirii, N. irregularis, Assilina granolosa, A. leymeriei, A. laminosa Rotalia trochidiformis, Discocyclina ranikotensis* and *Fasciolites oblonga*. The age of the Nammal Formation is Late Paleocene to Eocene.

With increase in limestone beds the Nammal Formation transitionally passes into the overlying **Sakesar Limestone** (GEE 1935, FATMI 1973), the type locality of which is the Sakesar Peak (32° 31'30"N; 71° 36'E). It consists of grey, nodular to massive limestone which is cherty in the upper part. Near Daudkhel, the Sakesar Limestone laterally grades into massive gypsum. Its thickness ranges from 70 m to about 300 m. It contains, amongst others, *Nummulites atacicus, N. mamilla, Assilina granulosa, A. leymeriei, A. subspinosa, Fasciolites oblonga, F. globosa, Lockhartia conditi, L. hunti, Operculina nummulitoides, Orbitolites complanatus* and *Rotalia trochidiformis*. Its age is Early Eocene.

The **Chor Gali Formation** (PASCOE 1920, FATMI 1973) rests conformably on the Sakesar Limestone (type locality Chor Gali Pass, 33° 26'30"N; 70° 41'E). It consists largely, in the lower part, of thin-bedded grey, partly dolomitized and argillaceous limestone with bituminous odour, and, in the upper part, of greenish, soft calcareous shale with interbeds of limestone. Its thickness ranges from 30 m to 140 m. It contains molluscs, osctracods and foraminifera (DAVIES 1937, EAMES 1952, GILL 1953, LATIF 1970 c). The more significant, larger foraminifera include *Assilina spinosa, A. granulosa, A. daviesi, Flosculina globosa, globorotalia ressi, Lockharti hunti, L. tipperi, L. conditi, Nummulites atacicus, N. mamilla, Orbitolites complanatus, Rotalia crookshanki, R. trochidiformis* etc. The age of the Chor Gali Formation is Early Eocene. It is overlain unconformably by the Neogene sequence.

In the Kohat area, the Eocene sequence conformably rests on the Paleocene Patala Formation and includes the Panoba Shale (with Bahadur Khel Salt), the Shekhan Formation, the Kuldana Formation and the Kohat Formation. The **Panoba Shale** (EAMES 1952, FATMI 1973; type locality south of Panoba village, 33° 37'N; 71° 35'E) consists of grey to olive, silty and calcareous shale with burrow markings. At places it is ferruginuous, gypsiferous, and contains subordinate alum shale or thin flaggy limestone. Southwards (Bahadur Khel, 33° 08'54"N; 70° 59'53"E) it grades into the **Bahadur Khel Salt Formation** (GEE 1945, MEISSNER et al. 1968). The Panoba Shale is 40 m to 160 m thick and contains *Globorotalia acqua, G. quadrata, Assilina postulosa, Orbitolites complanatus* and *Nummulites* sp. The age of the Panoba Shale is Early Eocene.

The **Shekhan Formation** (DAVIES 1926 b, FATMI 1973), type section Shekhan Nala (33° 35'40"N; 71° 30'30"E), rests conformably on the Panoba Shale and consists of yellow to grey, thin-bedded to massive, nodular limestone in the lower part, and gypsiferous shale in the upper part. In the vicinity of Marri Khel, the upper part becomes gypsiferous, and farther south in the Jatta area (33° 18'N; 71° 17'E) the Formation grades into the Jatta Gypsum Formation (MEISSNER et al. 1968). Its thickness ranges from about 50 m to over 70 m. It contains foraminifera, molluscs, echinoids and corals (EAMES 1952, NAGAPPA 1959, PASCOE 1963). The larger foraminifera include *Assilina daviesi, A. laminosa, Nummulites atacicus, N. pinfoldi, Orbitolites complanatus, Discocyclina* sp., *Operculine* sp. and *Fasciolites oblonga* etc. The echinoids include *Conoclypeus pilgrimi* and *Hemiaster digonus*. The age of the Shekhan Formation is Early Eocene.

The **Kuldana Formation** (WYNNE 1874, FATMI 1973; type locality Kuldana, 33° 56'N; 73° 27'E) conformably overlies the Shekhan and the Jatta Gypsum Formations. It consists dominantly of vari-coloured gypsiferous and arenaceous shale and brown to grey, gypsiferous marl, interbedded with red sandstone and calcareous conglomerate. It is about 17 m to over 160 m thick. It contains foraminifera, oysters and fresh water gastropods. Vertebrate remains were found in the middle part (PINFOLD 1918, MEISSNER et al. 1968). *Assilina granulosa, A. subspinosa, A. exponens* have been reported from Hazara (LATIF 1970 c), and *Gaudryina. Lockhartia (L. hunti)* has been reported from Kohat (MEISSNER et al. 1968). The Formation has been assigned an early Middle Eocene to Late Eocene age.

The **Kohat Formation** (DAVIES 1926 a, MEISSNER et al. 1968, FATMI 1973), with the type locality southwest of the village Gambat (33° 27'N; 71° 35'E), rests on the Kuldana Formation conformably. It consists mainly of grey to cream-coloured, massive, nodular limestone and olive shale. It includes a lower **Kaladhand Limestone Member**, a middle **Sadkal Shal Member**, and an upper **Habib Rahi Limestone Member**. The Kohat Formation ranges in thickness from 50 m to 170 m and contains *Assilina* *postulosa, A. granulosa, Fasciolites oblonga, Disctyoconoides vredenburgi, Flosculina globosa, Lockhartia hunti, Nummulites mammilla* and *Orbitolites complanatus.* It is Eocene in age. The Kohat Formation is overlain unconformably by the Neogene sequence which has a thin conglomerate at the base.

In the Potwar, Kalachitta and Hazara areas, the Eocene sequence overlies the Paleocene Patala Formation conformably and includes the Margalla Hill Limestone, the Chor Gali Formation, and the Kuldana Formation. The Kohat Formation overlies the Kuldana Formation in parts of the Potwar area and is missing in the Kalachitta and Hazara areas. The **Margalla Hill Limestone** (LATIF 1970 a, FATMI 1973; type locality Burjianwala, 33° 39'N; 12° 19'10"E) consists largely of grey, medium-bedded to massive, nodular limestone with subordinate marl and shale. The Formation ranges in thickness from about 80 m to 120 m and contains *Assilina granulosa, A. spinosa, A. dandodica, Discocylina ranikotensis, Lockhartia conditi, L. hunti, L. tipperi, Fasciolites delicatissimus, F. ellipticus, Lepidocyclina punjabensis, Nummulites atacicus, N. globulus, N. mammilla, Operculina jiwani, O. patalensis, Rotalia trochidiformis.* The Margalla Hill Limestone is Early Eocene in age.

The overlying Chor Gali, Kuldana and Kohat Formations have been described earlier. The Palaeogene sequence in the Potwar, Kalachitta and Hazara areas is unconformably overlain by Neogene formations.

3.43 Neogene

In the West Pakistan Foldbelt, the Neogene sequences consist mostly of flysch sediments comprising basin turbidites, slope, shelf and near shore deposits. These are capped by Pleistocene molasse-type deposits. Hunting Survey Corp. (1960) divided this sequence into a number of formations the names of which were adapted by other workers (HARMES et al. 1984, RAZA et al. 1990). However, the Geological Survey of Pakistan (CHEEMA et al. 1977) have classified these units into fewer sub-divisions, shown in Fig. 3.9. Based on this classification, the Neogene sequence of this region is described below.

The **Hinglaj Formation** (Fig. 3.9; VREDENBURG 1909 a, Hinglaj Group; CHEEMA et al. 1977) forms the lower part as well as the bulk of the Neogene succession in Baluchistan. The Hinglaj Mountains are considered as the type locality. The Formation rests transitionally on the Oligocene Khojak Formation, though in the southeastern part of the region, the Hinglaj Formation overlies unconformably the Nisai Formation, the Parh Limestone and other older rocks, with a conglomerate at the base. The Formation consists of sandstone with mudstone, shale, shelly limestone and minor conglomerate. The sandstone is grey to brown, thin- to thick-bedded, cross-stratified, ripple-marked, calcareous and protoquartzitic. The shale is grey to brown and grades into mudstone. The limestone is commonly present in the lower part and it is grey, shelly to coquinoid, and argillaceous to sandy. In the Makran region, the Formation includes a lower **Parkini Mudstone Member** (Fig. 3.12), which is nodular and dark grey, and an upper **Chatti Mudstone Member** which is more calcareous and marly. The thickness of the Formation ranges from 3,030 m to over 4,545 m. The Formation

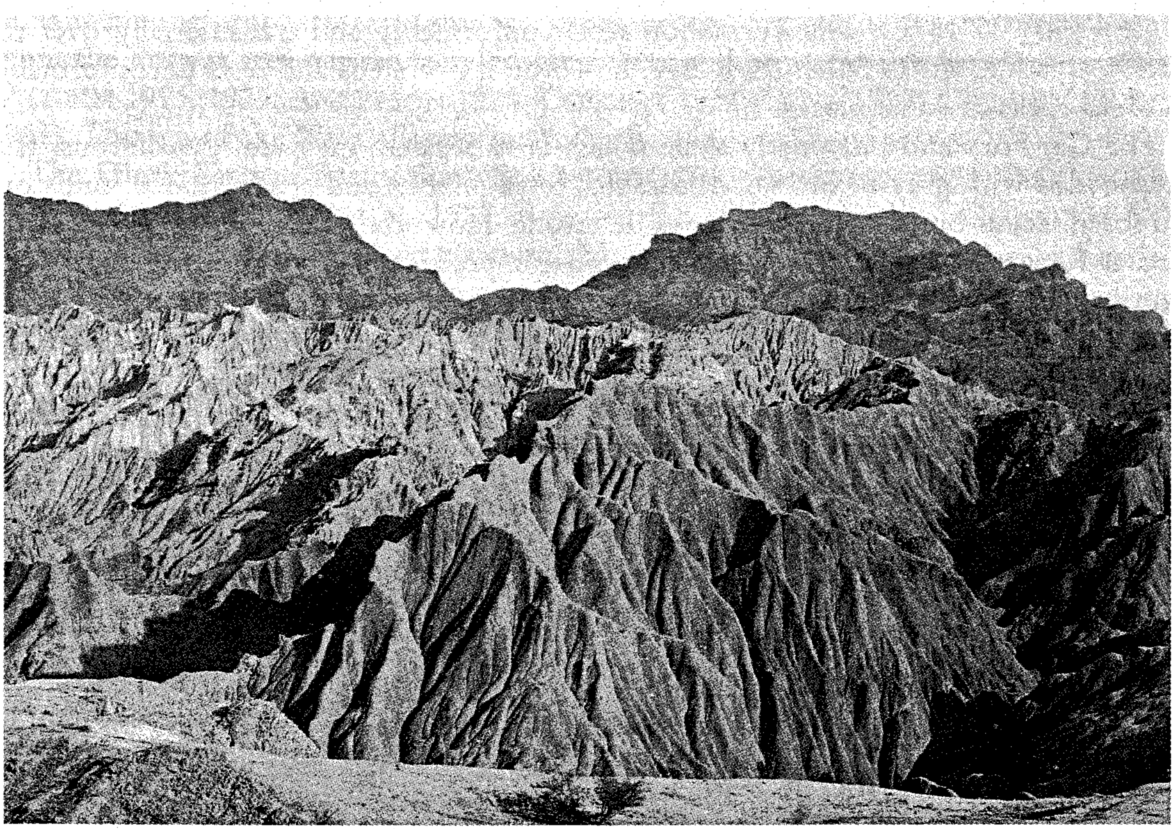


Fig. 3.12. Parkini Mudstone Member of Miocene-Pliocene age, mud intrusion into the overlying sandstone of the deltaic Talar Sandstone of Pliocene age. View to the south to Liddha Koh (1,020 m). Makran area, Jau Pass west of Bela, Baluchistan (Photo: D. BANNERT).

contains foraminifera, gastropods and bivalves (Hunting Survey Corp. 1960). The age of the Hinglaj Formation ranges from Miocene to Pleistocene.

The **Gwadar Formation** (VREDENBURG 1921, Hunting Survey Corp. 1960, CHEEMA et al. 1977; type section in Gwadar Peninsula) overlies the Hinglaj Formation unconformably. It consists of soft, poorly consolidated, poorly-bedded or massive, buff coloured sandy clays, interbedded with subordinate brown medium- and coarse- grained poorly-consolidated, thick-bedded, sandstone and a few beds of conglomerate. The thickness of the Formation ranges from 60 m to about 900 m. It contains foraminifera, bivalves and gastropods and has been assigned a Late Pliocene to Pleistocene age.

In the West Pakistan Foldbelt, the Neogene sedimentary rocks are exposed mainly in faulted thrust blocks of the Hinglaj Formation or the Gaj Formation, flanked by outcrops of the Siwalik Group and the Bostan Formation. The Hinglaj and Bostan Formations have been described earlier whereas the others are discussed in the following paragraphs (Figs. 3.8, 3.9):

In the Kirthar and Sulaiman Ranges the lower part of the Neogene consists of marine, near shore to estuarine sediments of the **Gaj Formation** (BLANFORD 1876, WILLIAMS 1959, PASCOE 1963, CHEEMA et al. 1977). The type locality is at the Gaj River, 26°

51'40"N; 67° 17'18"E). The Formation rests conformably and transitionally over the Nari Formation. In the Sulaiman Range, however, it oversteps and rests unconformably on older rocks at some places.

The Gaj Formation is mostly shale which is variegated, grey and gypsiferous. It is interbedded with grey to brown, calcareous, ferruginuous and cross-bedded sandstone and fossiliferous brownish, argillaceous limestone. However, in the southern part of the Kirthar Ranges in the Karachi area, the Formation predominantly consists of yellowish-brown sandstone and cream-coloured, or pinkish-white argillaceous limestone. Its thickness ranges from about 90 m in the Quetta area to 600 m – 750 m in the Kirthar area. The Formation contains foraminifera, molluscs, echinoids, bryozoans, corals and other fossils (Duncan & Sladen 1885, Nuttall 1926, Vredenburg 1928, Hunting Survey Corp. 1960, Khan 1968, Cheema 1977). Some of the more significant fossils include *Miogypsina globulina, M. cushmani, Lepidocyclina marginata, L. blanfordi, Ostrea vestita, Glycimeris (Pectunculus) sindensis; Breynia carinata, Clypeaster depressus* and *Caleloplearus frobesi.* The Gaj Formation is Early Miocene (Aquitanian to Burdigalian) in age but in places may extend into the Middle Miocene (Pascoe 1963, Khan 1968).

In the Kirthar and Sulaiman Ranges, the Gaj Formation is overlain by the **Siwalik Group** (Meddlicot 1864, Oldham 1893, Holland et al. 1913, Pilgrim 1913, Lewis 1937, Danilchik et al. 1967, Cheema 1977) which is composed of molasse-type sediments. The Siwalik Group overlies the Gaj Formation conformably, though at several places, particularly in the Sulaiman Range, it overlaps the older Formations. An angular unconformity may be seen at some places. The term Siwalik Group now includes the "Manchar Series" of Blanford (1876) and Vredenburg (1906), the Sibi and Urak Group of Hunting Survey Corp. (1960) and the Uzhda Pasha Formation, the Shinmati Formation and the Urak Conglomerate of Kazmi (1961, Kazmi et al. 1970). The Siwalik Group includes (in ascending order) the Chinji, Nagri, Dhok Pathan and Soan Formations, and the Lei Conglomerate.

The **Chinji Formation** (Pilgrim 1913, Lewis 1937, Eames 1952, Cheema 1977; type section south of Chinji Village, 32° 41'N; 72° 22'E) is confined to the eastern Sulaiman Range and the Kohat-Potwar region, and is not developed in the Kirthar area. In the Sulaiman Range, it overlies the Nari Formation disconformably and consists mainly of red clays with subordinate grey to brown, fine- to medium-grained, gritty, soft, cross-bedded sandstone. The Formation has yielded a rich vertebrate fauna of crocodiles, turtles, monitor lizards, aquatic birds, dinotheres, primitive trilophodonts, *suidae*, water deer, hominoides, pythons and *chelonias* (Pilgim 1913, Mathew 1929, Colbert 1933, Lewis 1937, Pascoe 1963). The age of the Chinji Formation is Late Miocene (Late Tortonian to Sarmatian).

The **Nagri Formation** (Pilgrim 1913, 1926, Lewis 1937, Cheema 1977; type locality Nagri village, 32° 45'N; 72° 14'E; principal reference section at Gaj River, 26° 51'N; 67° 17'E) rests conformably on the Chinji Formation in most places in the Sulaiman Range, though elsewhere in the Sulaiman and Kirthar Ranges it overlies the Gaj and earlier Formations unconformably. At some places an angular unconformity may be seen. The Formation is largely thick-bedded to massive greenish-grey, medium- to coarse-grained, salt and pepper textured, calcareous sandstone, interbedded with subordinate brown to reddish sandy clay and conglomerate. The thickness of the Formation ranges from 200 m to 3,000 m. The Formation has yielded a rich vertebrate fauna including proboscideans, rhinoceratides, crocodiles, chelonions and artiodactyles. From the Potwar area perissodactyles, carnivores and primates also have been reported (PILGRIM 1913, 1926, ANDERSON 1928, COLBERT 1933, LEWIS 1937, GILL 1952, PASCOE 1963). The age of the Nagri Formation is Early Pliocene (Pontian).

The **Dhok Pathan Formation** (BLANFORD 1876, GRIESBACH 1893, PILGRIM 1913, COTTER 1933, CHEEMA et al. 1977; type section at Dhok Pathan village, 33° 07'N; 72° 14'E) has a transitional contact with the underlying Nagri Formation and consists of a thick pile of interbeded sandstone and clay. The sandstone is thick-bedded, grey to brown, calcareous and cross-bedded; the clay is brown, orange to red. Lenses of conglomerate are present in the upper part. Its thickness ranges from about 1,330 m to over 2,000 m. A rich vertebrate fauna has been obtained from the Formation. It is less fossiliferous in the Sulaiman and Kirthar Ranges where *Hipperion punjabiense, Rhinoceros sivalensis* and *Pachyportax latidens* have been found. The Potwar region has, however, yielded a much richer vertebrate fauna including carnivora, proboscidea; perissodactyla and arthiodactyla (PASCOE 1963). The age of the Formation is Early to Middle Pliocene.

The **Soan Formation** (MEDDLICOT 1864, BLANFORD 1876, PILGRIM 1913, KRAVTCHENKO 1964, CHEEMA et al. 1977; type section near Mujahad village, 32° 22'N; 72° 47'E; principal reference section near Urak village, 30° 15'N; 67° 11'E) rests disconformably on the Dhok Pathan Formation with a marked coarsening of the clastic sediments and appearance of massive conglomerate beds. The Formation largely consists of massive conglomerate with subordinate sandstone, siltstone and clay. The pebbles and boulders in the conglomerate range from 5 cm to 30 cm. The Soan Formation is 300 m to 3,000 m thick. It is poorly fossiliferous and vertebrates such as *Mastodon sivalensis, Stegodon clifti, Elephas planifrons, Sivatherium giganteum, Proamphibos lachrymans, Dichoryphochoerus durandi* and *Sivafelis potens* have been reported from the Potwar region. The age of the Soan Formation is Late Pliocene to Early Pleistocene (Astian to Villafranchian).

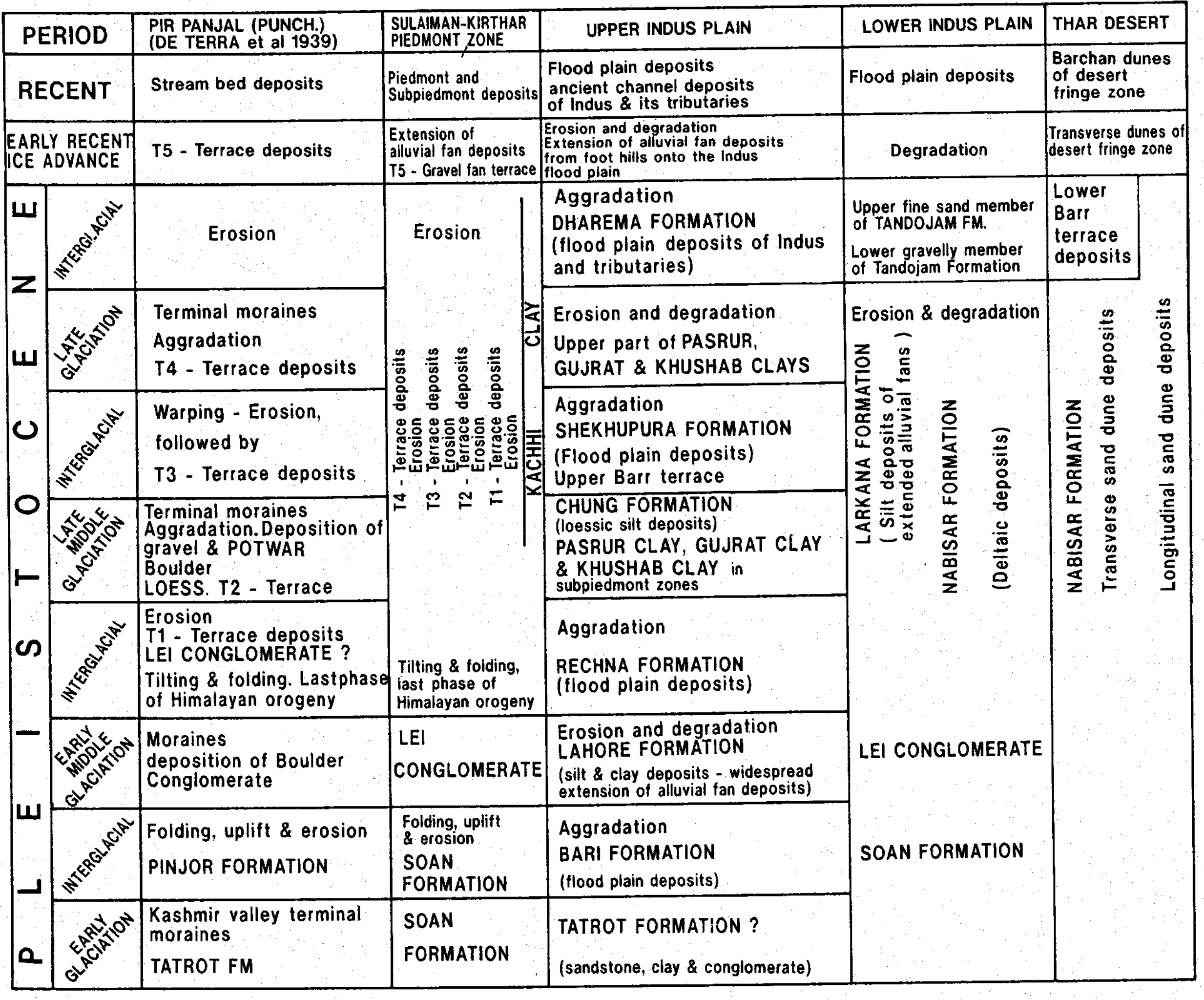
The Neogene sequence in the Kohat-Potwar region consists entirely of fluvial sediments of the Siwalik Group and the Rawalpindi Group (PINFOLD in CHEEMA et al. 1977). The rocks of the Siwalik Group have been described earlier. The **Rawalpindi Group** rests disconformably on various Eocene formations and it correlates with the Gaj Formation of the Kirthar and Sulaiman region. It includes the Murree and Kamlial Formations.

The **Murree Formation** (WYNNE 1874, PILGRIM 1910, CHEEMA et al. 1977; type section north of Dhok Maiki, 33° 25'N; 72° 35'E) is a thick monotonous sequence of red and purple clay, and interbedded greyish sandstone with subordinate intraformational conglomerate. The thickness of the Formation increases from 180 m to 600 m in the Salt Range to 3,030 m in the northern Potwar area. It is poorly fossiliferous though plant remains and some vertebrate bones have been found including those of *Anthracotherium bugtiense, Brachyodus gigantens, Palaeochoerus pascoei, Hemimeryx* sp. and *Teleoceras fatehjangensis*. This fauna indicates an Early Miocene age of the Murree Formation.

The **Kamlial Formation** (PINFOLD 1918, LEWIS 1937, PASCOE 1963, FATMI 1973, CHEEMA et al. 1977; type section southwest of Kamlial, 33° 15'N; 72° 50'E) overlies the Murree Formation conformably and transitionally; though at some localities, it lies unconformably on the Eocene Sakesar Limestone. The Formation consists mainly of grey to brick-red medium- to coarse-grained sandstone interbedded with purple shale and intraformational conglomerate. A number of mammalian fossils have been found including *Listriodon pentapotramiae, Hemimeryx blanfordi, Anthracotherium* sp., *Trilophodon* cf. *angustidens, Dinotherium indicum* and *Hyaenae lurus lahirii* (PASCOE 1963). The age of the Kamlial Formation is Middle to Late Miocene.

3.44 Quaternary

Quaternary stratigraphic sequences in Pakistan represent a wide range of depositional environments (Fig. 3.13, 3.14) including the marine coastal region shore and offshore deposits, the volcanic deposits of the Koh-i-Sultan, the aeolian deposits of the Thar and other deserts, evaporites of the salt lakes in Sindh, playa and lacustrine deposits in the intermountain basins, deeply-weathered residual soils in the Himalayas, glacial and fluvioglacial deposits in the Himalayas, Karakorum and Hindukush Ranges, and



PERIOD		PIR PANJAL (PUNCH.) (DE TERRA et al 1939)	SULAIMAN-KIRTHAR PIEDMONT ZONE	UPPER INDUS PLAIN	LOWER INDUS PLAIN	THAR DESERT
RECENT		Stream bed deposits	Piedmont and Subpiedmont deposits	Flood plain deposits ancient channel deposits of Indus & its tributaries	Flood plain deposits	Barchan dunes of desert fringe zone
EARLY RECENT ICE ADVANCE		T5 - Terrace deposits	Extension of alluvial fan deposits T5 - Gravel fan terrace	Erosion and degradation Extension of alluvial fan deposits from foot hills onto the Indus flood plain	Degradation	Transverse dunes of desert fringe zone
PLEISTOCENE	INTERGLACIAL	Erosion	Erosion	Aggradation DHAREMA FORMATION (flood plain deposits of Indus and tributaries)	Upper fine sand member of TANDOJAM FM. Lower gravelly member of Tandojam Formation	Lower Barr terrace deposits
	LATE GLACIATION	Terminal moraines Aggradation T4 - Terrace deposits	T4 - Terrace deposits Erosion T3 - Terrace deposits Erosion T2 - Terrace deposits Erosion T1 - Terrace deposits Erosion KACHHI CLAY	Erosion and degradation Upper part of PASRUR, GUJRAT & KHUSHAB CLAYS	Erosion & degradation LARKANA FORMATION (Silt deposits of extended alluvial fans) NABISAR FORMATION (Deltaic deposits)	NABISAR FORMATION Transverse sand dune deposits Longitudinal sand dune deposits
	INTERGLACIAL	Warping - Erosion, followed by T3 - Terrace deposits		Aggradation SHEKHUPURA FORMATION (Flood plain deposits) Upper Barr terrace		
	LATE MIDDLE GLACIATION	Terminal moraines Aggradation. Deposition of gravel & POTWAR Boulder LOESS. T2 - Terrace		CHUNG FORMATION (loessic silt deposits) PASRUR CLAY, GUJRAT CLAY & KHUSHAB CLAY in subpiedmont zones		
	INTERGLACIAL	Erosion T1 - Terrace deposits LEI CONGLOMERATE ? Tilting & folding. Lastphase of Himalayan orogeny	Tilting & folding, last phase of Himalayan orogeny	Aggradation RECHNA FORMATION (flood plain deposits)		
	EARLY MIDDLE GLACIATION	Moraines deposition of Boulder Conglomerate	LEI CONGLOMERATE	Erosion and degradation LAHORE FORMATION (silt & clay deposits - widespread extension of alluvial fan deposits)	LEI CONGLOMERATE	
	INTERGLACIAL	Folding, uplift & erosion PINJOR FORMATION	Folding, uplift & erosion SOAN FORMATION	Aggradation BARI FORMATION (flood plain deposits)	SOAN FORMATION	
	EARLY GLACIATION	Kashmir valley terminal moraines TATROT FM	SOAN FORMATION	TATROT FORMATION ? (sandstone, clay & conglomerate)		

Fig. 3.13. Quaternary sequences of the Indus Plain and adjacent regions (after KAZMI 1977).

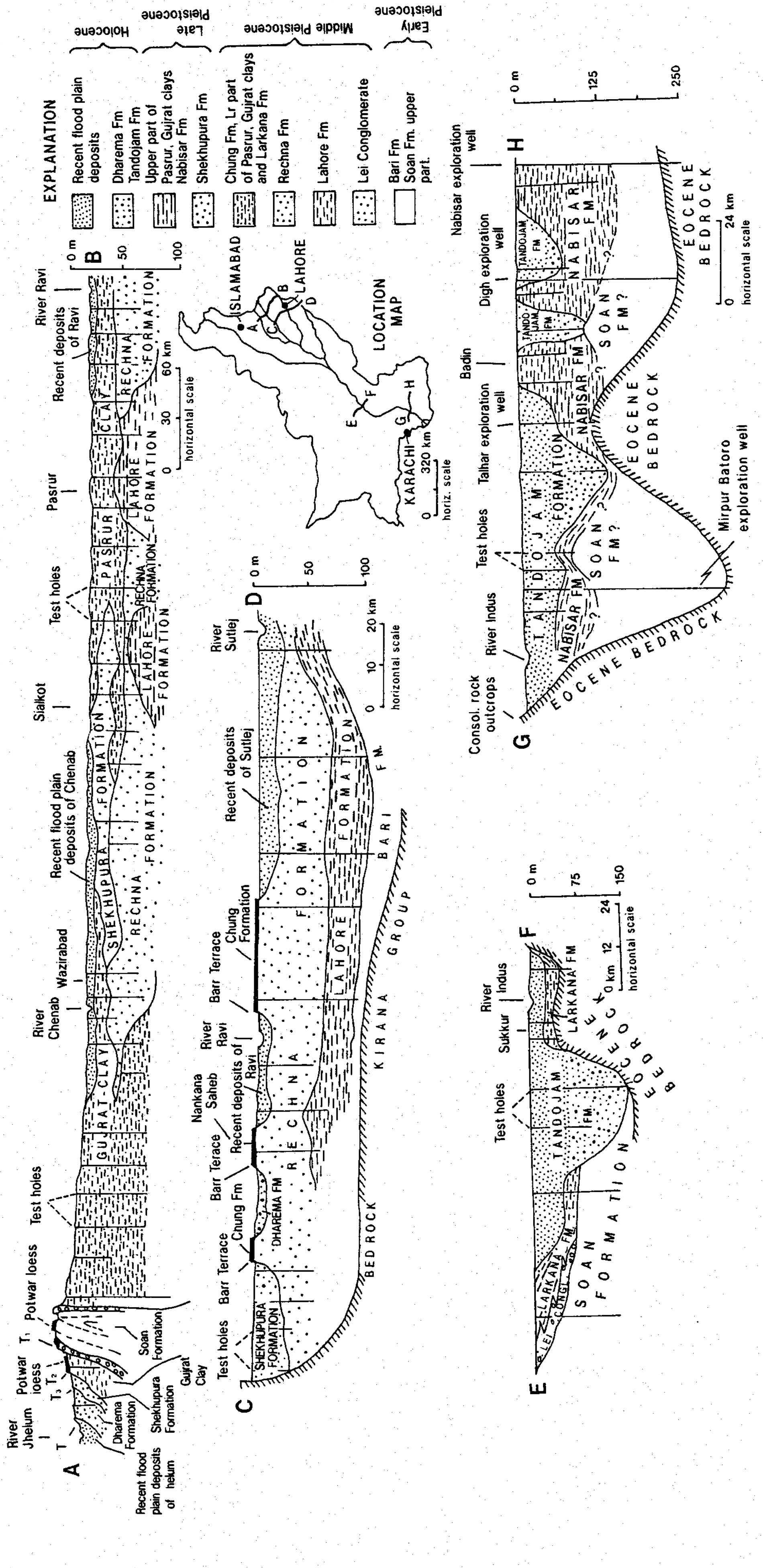


Fig. 3.14. Subsurface geological sections of the Quaternary sequences of the Indus Plain (after KAZMI 1977).

a complex of fluvial deposits in the vast piedmont zone, flood plain and delta of the Indus River.

On the Makran coast the Late Pliocene to Pleistocene Gwadar Formation is overlain by the **Jiwani Formation** (Fig. 3.9; Hunting Survey Corp. 1960; type section east of Jiwani) with an angular unconformity on top of the Gwadar Formation. At places it overlies the Hinglaj Formation unconformably. The Jiwani Formation consists of littoral deposits of shelly limestone, sandstone and conglomerate. The limestone is comprised of shelly fragments set in a sandy calcareous matrix. It is medium- to thick-bedded, hard and porous. The sandstone is thin- to thick-bedded, cross-laminated, pebbly, medium- to coarse-grained and well sorted. The Formation is about 30 m thick and contains bivalves such as *Fassularca pectunculiformis, Timoclea arakanensis, Martesia striata, Ostrea pseudocrassissima* and other fossils. The Jiwani Formation has been assigned a Pleistocene to sub-Recent age by Hunting Survey Corp. (1960).

In the intermountain basins a thick sequence of conglomerate with subordinate sandstone and some mudstone commonly rests unconformably over the Neogene or earlier deposits. These conglomerates have been deformed and folded and form basinal deposits. In the Baluchistan region they have been named **Haro Conglomerate** (Hunting Survey Corp. 1960, type locality is the Kech Valley in the Kharan District). In the Indus Basin similar conglomerates have been named the **Lei Conglomerate** (GILL 1952, CHEEMA et al. 1977; type locality Lei River section southeast of Rawalpindi, principal reference section near Spintangi railway station). They were previously given different names by various authors (PILGRIM 1910, GEE 1945, 1983, Hunting Survey Corp. 1960, KAZMI 1961, PASCOE 1963, KAZMI et al. 1970). The conglomerate is largely comprised of rounded to subrounded pebbles and boulders. Its thickness ranges from about 150 m to over 900 m. The Lei Conglomerate has yielded pre-Soan artifacts and vertebrate fossils including *Elephas hysudricus, Sivatherium giganteum, Dicerorhinus platyrhinus, Equus* sp., *Bos.* sp., and *Camels* sp. (PILGRIM 1913, WADIA 1928, PASCOE 1963). The Lei Conglomerate has been related to the last major episode of the Himalayan orogeny and has been assigned a Pleistocene age (PASCOE 1963, Hunting Survey Corp. 1960).

In the Quetta area a thick sequence of folded lacustrine to playa-type deposits forms the valley fills and unconformably overlies the Neogene and earlier rocks. These deposits have been named the **Bostan Formation** (Hunting Survey Corp. 1960; type sections Pishin Lora and Kamerod Village in the Siahan Range). This Formation overlies the older formations (including Jurassic), generally with a marked angular unconformity. However, in the Dalbandin Valley it is believed to be transitional with the Khojak Formation. It consists of gently folded basinal deposits that were laid down in tectonic depressions. It consists mainly of white, grey to brick-red, poorly consolidated, gypsiferous clays interbedded with subordinate reddish-brown to grey, salt and pepper textured, thin-bedded sandstone and conglomerate. No fossils have yet been reported from the Formation. The Bostan Formation is believed to be Pleistocene in age.

The intermountain basins and the mountain valleys outside the glaciated areas are largely covered with Quaternary alluvial valley fills which, at many localities, consists of interbedded fluvial, aeolian (loessic), lacustrine and playa deposits (KAZMI et al. 1970, BURBANK et al. 1985). The Thar Desert along the eastern margin of the Indus Plain is largely covered with longitudinal and complex seif-type stabilized sand dunes. Some of the longitudinal sand dune ridges have a relief of as much as 100 m and are more than 40 km long (KAZMI 1977, 1985). The interdunal depressions are filled with playa-type Recent sediments or contain salt lakes. The aeolian deposits of the Thar and Cholistan Deserts range in age from Pleistocene to Recent (see also Chapter 11.12; KAZMI 1977).

In some regions of Pakistan such as Hazara, Swat, the Pir Panjal Range and the western Himalayas, remnants of relict landscapes in the form of ancient valley or basin floors that have escaped Recent erosion are still preserved (GRINLINTON 1928, DETERRA 1935, PORTER 1970, LAWRENCE 1985). Some of the relicts like those of the Chattar Plain of Hazara are covered with thick residual soils. In the Chattar Plain, the upper part of the soil comprises a thick clay-rich saprolite with core stones at depth resting over disintegrated or jointed bed rock. These soils have formed over a prolonged period of tropical weathering in an area of low relief. LAWRENCE et al. (1985) believe that these soils developed as a result of prolonged weathering between 20 to 5 mio. years ago, and were intermittently eroded due to the Himalayan uplift of the past 5 mio. years. The author of this Chapter, however, is of the view that these relict residual soils are essentially of Pleistocene age. It is most unlikely that these soils could have escaped severe tectonics and uplift, particularly during the past 4 to 5 mio. years (ZEITLER et al. 1982), and the Pleistocene glaciations.

Pleistocene to Recent glacial moraines, fluvioglacial deposits, loess, glacial lake deposits, ancient rock terraces as well as fluvial terraces are commonly seen in the upper reaches of the Chitral, Swat, Hunza and Indus Valleys. Three major episodes of Pleistocene glaciation have been described by SHRODER et al. (1989) in the Indus Valley between Darel and Gilgit. OLSON (1982), PORTER (1970), CRONIN (1982), CRONIN et al. (1989), and DETERRA et al. (1939) also have described the Quaternary deposits in the upper Indus Valley, in the Swat Valley, in the Skardu depression and in the Kashmir-Potwar area. The earlier work by PATTERSON et al. (1939) had established four major glaciations in the Himalayas during the Pleistocene on the evidence of distinct glacial moraines.

CRONIN (1982) has described an early Pleistocene sequence, the **Bunthang Sequence** from the Skardu Valley, which has been divided into a lower, middle and upper part (Fig. 3.15). The Lower Bunthang sequence consists of a till at the base overlain by a locally deformed fluvial to glacio-lacustrine conglomerate and sandstone. It grades upwards into grey, massive siltstone and mudstone. The Middle Bunthang Sequence rests on the lower one and is comprised of three wedge-shaped units of boulder conglomerates. It is overlain by the Upper Bunthang Sequence of fine-grained sandstone and massive mudstone interpreted as braided stream deposits. The Bunthang Sequence is about 1,200 m thick and is overlain by alluvial terrace deposits. The upper age limit of the sequence, based on magnetic polarity studies (end of Matuyama Chron), is 0.73 mio. years (CRONIN et al. 1989). The initial age is uncertain and according to CRONIN et al. (1989) it is likely to synchronise with the onset of the Late Cenozoic Glaciation around 3.2 mio. years ago in the Northern Hemisphere.

The Quaternary deposits of the upper Indus Valley between Darel and Gilgit and in the Hunza Valley include glacial moraines, tills and fluvioglacial deposits, lake deposits and fluvial deposits ranging in age from Early Pleistocene to the Recent (DERBYSHIRE et al. 1981, SHRODER et al. 1989). Three periods of major glaciation have

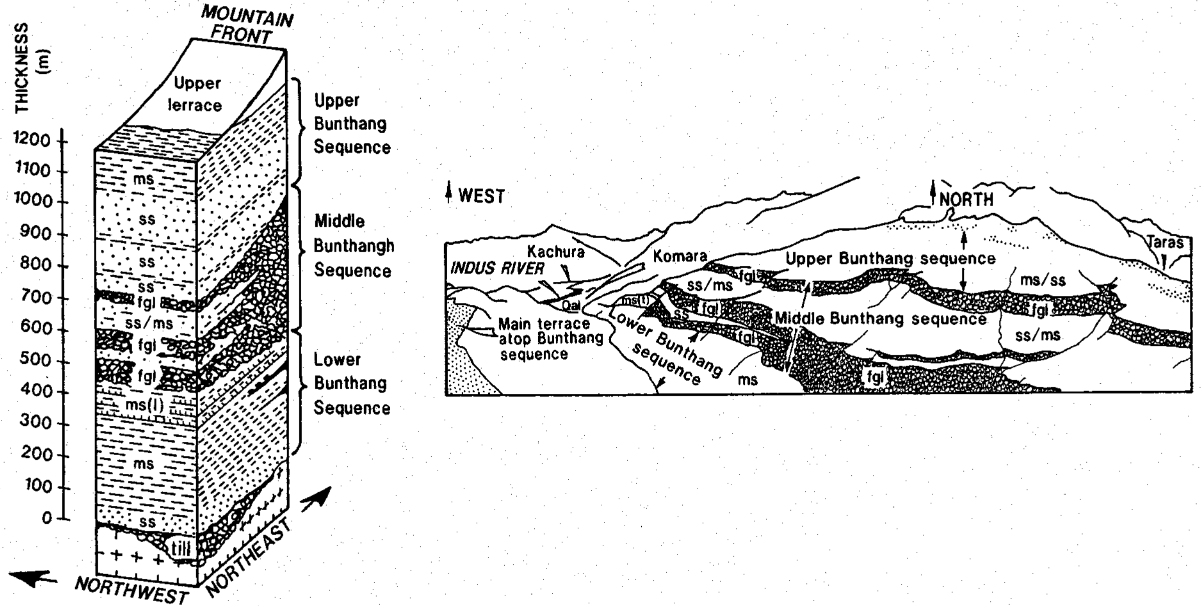
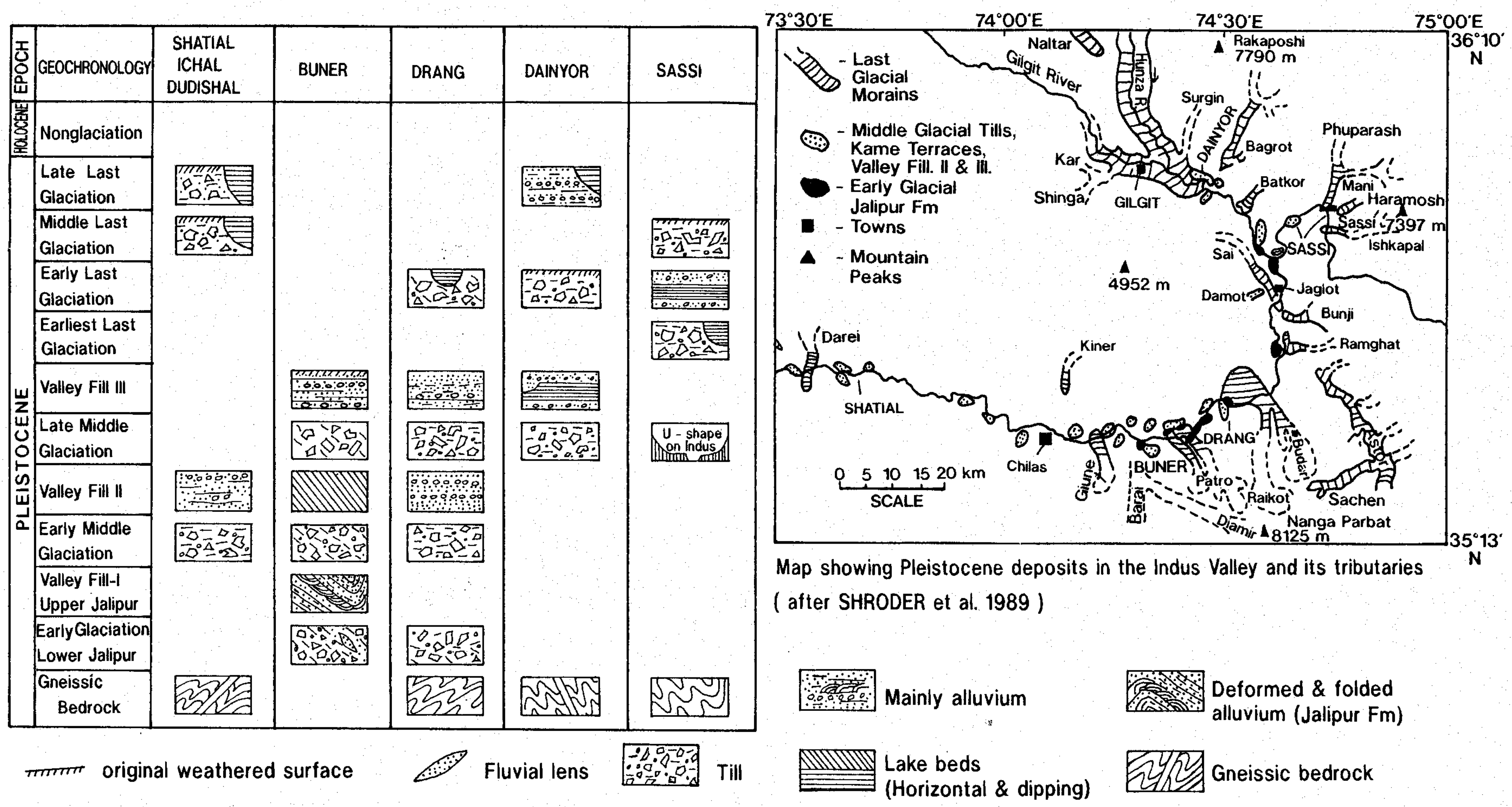


Fig. 3.15. Panoramic view of the Bunthang Sequence in the Ghothamal Canyon near Skardu. The section on the left shows the stratigraphy of the Bunthang Sequence: ms = mudstone, Ms(t) = rhythmically bedded musdtone, ss = sandstone, fgl = fanglomerate, Qal = younger alluvium, cross pattern igneous/metamorphic basement,(after CRONIN et al. 1989).

been identified, with the middle glaciation having two and the last having four phases of ice advance. The geochronology has been compiled using data from thermoluminiscence, magnetostratigraphy and fission track dates. These deposits are shown in Fig. 3.16.

The vast alluvial plain of the Indus River and its tributaries extends over an area of about 100,000 km^2 and contains fluvial deposits which are at places over 500 m thick and range in age from Pleistocene to Recent. Data from several hundred water wells drilled in the Indus Plain (KAZMI 1964) provided a lucid picture of the nature, structure and stratigraphy of these Quaternary deposits. KAZMI (1966, 1977, 1984) has worked out the Quaternary stratigraphy of the Indus alluvium and has correlated it with the Himalayan Quaternary sequence of DETERRA et al. (1939). This chronology is based on the following thesis:

Present day ephemeral or intermittent streams draining the outer hill ranges around the Indus Plain carry heavy silt loads, which are deposited as wide and thick silt and clay deposits in the piedmont zone. The Indus and its major perennial tributary streams, however, carry a relatively low silt and high sand load. During glacial periods most of the precipitation in the catchment of the perennial Himalayan rivers would have been in the form of snow, thus reducing the seasonal flood discharge and the deposition on the flood plains would have been reduced. On the other hand during the pluvial periods, the rainfall on the outer hill ranges fringing the Indus Plain and the deposition of silt in the Piedmont zone would have increased. The silt and clay deposits (**Pasrur, Gujrat** and **Khushab Clays, Larkana** and **Lahore Formations**; Figs. 3.13, 3.14) were thus formed and overlapped the flood plain deposits. Lowering of the sea level during each glaciation would have degraded and entrenched the Indus and its tributaries into relatively narrow channels forming terraces and causing extensive desertification



Map showing Pleistocene deposits in the Indus Valley and its tributaries (after SHRODER et al. 1989)

Fig. 3.16. Quaternary sequence of the upper Indus Valley. Localities shown on the map on the right (after SHRODER et al. 1989).

amongst other physiographic changes. The **Potwar Loess, Chung Formation** and the aeolian sand deposits of the Thar and Cholistan Deserts were thus formed. Each interglacial period must have caused widespread aggradation, extensive melting of the ice, dispersal of ice rafted boulders and erratics, channel filling with coarser, poorly sorted sand (**Tandojam Formation, Dharema Formation, Shekhupura Formation** and **Rechna Formation**), changes in river courses and the position of the Indus Delta, and the formation of wide flood plains and deltaic deposits (**Nabisar Formation**).

4. Igneous and metamorphic rocks

(FAIZ AHMAD SHAMS)

The history of the formation of igneous and metamorphic rocks in Pakistan is not fully unravelled, but recent detailed investigations have helped to clarify some of the spectacular events during petrotectonic evolution. This chapter reviews the characteristics, origin and evolution of these rocks as presently understood.

4.1 Igneous and metamorphic rocks of the Tethyan Belt

4.11 Indo-Pakistan Plate

4.111 South of the Main Mantle Thrust (MMT) Zone

The Shengus and Iskere Gneisses are the oldest rocks belonging to the Nanga Parbat Massif, with U/Pb ages of 2,500 mio years and 1,850 mio years respectively (ZEITLER et al. 1989).

The Nanga Parbat-Haramosh Massif antiformal structure, south of the MMT Zone (Fig. 2.4), represents an example of progressive metamorphism leading to granitization on batholithic scale (WADIA 1937, MISCH 1949). The protolith consists of the Archaean (?) to Middle Proterozoic Sharda Group (Fig. 3.2) rocks (CHAUDHRY & GHAZANFAR 1990), primarily slates, phyllites and marble, overlain conformably by Cretaceous-Eocene volcanics belonging to the Indus Flysch of DE TERRA (1935). Barrovian-type metamorphism produced, successively, phyllites with rotated albite porphyroblasts, garnetiferous phyllites, muscovite-garnet schists, muscovite-biotite-garnet-oligoclase schists, muscovite-biotite-garnet-kyanite-oligoclase gneisses and garnet-sillimanite-oligoclase gneisses. The central dome of the Massif includes granitic gneisses containing orthoclase, oligoclase-andesine, biotite, quartz and primary muscovite. Marble beds were transformed to lime-silicate rocks, having escaped granitization. A younger suite of fine-grained, massive-looking tourmaline granites and aplites formed lenticular masses, sills and dykes, many discordant to the gneissic foliation. Metamorphic isograds in the Massif are parallel to the strike of the metasediments and are nearly vertical. This indicates that the heat for metamorphism could have originated from depths (GANSSER 1964) and the source of heat could have been the alkalic fluids that caused compositional convergence of different lithologies of the Sharda Group (SHAMS & SHAFEEQ 1979). TRELOAR (1989) estimated the highest metamorphic conditions at sillimanite isograde with partial melting effects as having been 675° ± 50 °C and 11 ± 2 kb.

Garnets show two ages of formation: older garnets are slightly altered whereas the younger garnets are fresh. Garnets are also present as inclusions inside potash feldspar porphyroblasts/phenocrysts. Thus, two periods of metamorphism are indicated, with the later one coinciding with the granitization phenomenon (SHAMS & SHAFEEQ 1979). Mafic sheet intrusions were commonly changed to amphibolites; many of them cut the metamorphic fabric of the gneisses and migmatites. According to COWARD et al. (1986) the biotite gneiss of the Nanga Parbat developed from a porphyritic igneous granite that had intruded into migmatized pelites, psammites and marbles of polymetamorphic history.

The Nanga Parbat Massif has been undergoing uplift at a rate of 7 mm/year over the past 2 – 3 mio years. Ages as young as 2.3 mio years (ZEITLER 1985, ZEITLER et al. 1989), indicate that mineral and rock reconstitution may still be going on.

Rocks assigned to the Sharda Group continue south, southeast and southwest of the Nanga Parbat. In Azad Kashmir, the Group consists of high grade metamorphites, such as garnet-mica schists, garnet-kyanite gneisses, quartz-mica calc-gneisses, graphitic gneisses, marbles and amphibolites, along with sheet granites; above the kyanite grade of metamorphism, the rocks show effects of migmatization (GHAZANFAR et al. 1983). Similar relationships are observed in the upper Kaghan Valley, where the newly discovered Main Central Thrust (MCT) delineates a wedge-shaped closure of the "Nanga Parbat regime" (see Chapter 2.25).

Further west, to the Indus Valley, the basement complex of the Indo-Pakistan Plate is exposed in the Besham Antiform that resembles another but smaller "Nanga Parbat feature". Abutting against the Jijal Ultramafic Complex to the north, it is bounded by the Thakot and Puran Faults in the east and west respectively, which cut isograd surfaces of the Hazara and Swat Crystalline Zones (see Chapter 2.25). The Antiform is a tectonic window, which tapers off to the south under the drag of the Indus re-entrant. Rocks of the Besham Group exposed in this window (FLETCHER et al. 1986) include medium- to coarse-grained orthogneisses and biotite paragneisses, blue quartz and other pegmatites, marbles and amphibolites. Tectonic pods within these basement gneisses consist of quartzites, magnetite-bearing marbles, and lime-silicate skarns (Pazang Group of FLETCHER et al. 1986). These pods contain stratiform sulphide mineralization (see Chapter 8.4). The pelitic parts of the Pazang Group consist of feldspathic biotite schists, garnetiferous mica schists, micaceous quartzites and amphibole metapelites, commonly with pegmatite intrusions. Amphibolites are foliated basic sheets, associated with faults; they were syntectonically metamorphosed. Pegmatite dykes, as much as 20 m wide, are fairly common, composed of quartz, orthoclase-microperthite and oligoclase; they are undeformed to highly sheared. A suite of graphic-soda granites intruded the basement gneisses.

Toward the north, approaching the MMT Zone, the gneisses of the Besham Group begin to show layered structures conformable to the thrust plane, and gradually change into blastomylonites (LAWRENCE & GHAURI 1983).

The Besham basement gneiss has yielded a K/Ar age of 1,850 mio years (TRELOAR 1989) whereas the amphibolite revealed $^{40}Ar/^{39}Ar$ ages from more than 2,000 ± 6 mio years to 1,865 ± 3 mio years (BAIG & SNEE 1989), thus indicating metamorphic events during the Proterozoic. Notable is an intrusive soda granite dated 1,500 mio years (BAIG & SNEE 1989), showing the presence of a younger phase of magmatism and metamorphism.

Overlying the Besham Group (Fig. 3.2) unconformably are the rocks of the Karora Group (Fig. 3.2; FLETCHER et al. 1986; see Chapter 3.2) including a basal conglomerate, which contains clasts of the basement gneisses. The highest metamorphic grade observed in the Karora Group rocks is the biotite grade, with garnets up to 3 mm in diameter. Because of imbrication and thrust-stacking with the Besham basement gneisses, outcrops of the Karora Group show inverted metamorphic zones (TRELOAR 1989).

4.112 South of the Main Central Thrust (MCT) Zone

Precambrian rocks also occur here and include black slates, phyllitic slates, phyllites and sericite-chlorite schists. These rocks, which have suffered greenschist facies metamorphism, have been identified as the Dogra Slates by WADIA (1930). Mafic intrusive sheets are also present as chlorite schists, such as in the Poonch District of Azad Kashmir (Dogra Trap). These rocks extend northwestwards along the eastern flank of the Hazara-Kashmir Syntaxis (HKS). On the western flank of the HKS, the Hazara Slate (now named Hazara Formation; Fig. 3.2; CALKINS et al. 1975) is the equivalent of the Dogra Slates, consisting of slates, phyllites and phyllitic schists which have been metamorphosed to greenschist facies (CALKINS et al. 1975). Rb/Sr whole-rock ages of the Hazara Formation range from 728 mio years to 951 ± 20 mio years (CRAWFORD & DAVIES 1975), indicating a Late Proterozoic age for the metamorphism and deformation.

The Late Proterozoic Tanawal Formation (Fig. 3.2) includes the dominant lithologic sequence in the Hazara and Azad Kashmir Crystalline Zones (see Chapters 2.25, 3.1). The non-fossiliferous arenaceous facies in this sequence consists of quartzites, quartzitic schists and quartzitic sandstones, with inter-bedded arenaceous phyllitic slates and conglomerates. From the Panjal Thrust (PT) northwards in Hazara, successive Barrovian-type metamorphic grades are represented by chlorite, chloritoid, biotite, garnet, staurolite, kyanite and sillimanite. As a result of imbrication-thrusting, rocks of higher grade metamorphism are present at higher topographic levels, giving the impression of inverted metamorphic grades (SHAMS 1983, WILLIAMS 1989). The Tanawal metasediments are intruded by dolerites, diorites, epidiorites, porphyritic micro-tonalites, dacites, rhyodacites, pegmatites and quartz veins (TAHIRKHELI 1982). Many of the metamorphic index minerals exhibit multi-stage growth. Phyllonitic alteration/replacement is observed as a younger stage of retrograde metamorphism (SHAMS 1969); this phase even affected the granitic bodies that had intruded the Tanawal metasediments.

4.113 West of the River Indus

In the Swat Crystalline Zone, the Middle Proterozoic Manglaur Crystalline Schist (Fig. 3.2; Siliceous Schist Formation of MARTIN et al. 1962) is widely exposed, appearing also in a north-trending belt along the western flank of the Besham Antiform. This Formation includes quartz-mica schists, quartz-mica-garnet schists, quartz-mica-tourmaline schists, quartzites, schistose gneisses and amphibolite layers. The Manglaur Crystalline Schist is intruded by Swat Granite (WILLIAMS 1989), with a normal succession of metamorphic isogrades. Proterozoic schists reaching garnet grade of metamorphism have been described also from the Sakhakot-Qila area, Malakand Agency (ZULFIQAR 1990), and are believed to continue westward as well.

Granitic intrusions into the Tanawal Formation constitute the Hazara granitic complex, which forms a composite arcuate structure along with metasediments (FERNANDEZ 1983). The complex can be divided into an outer band of porphyritic Mansehra Granite and the inner body of Susalgali Gneiss (SHAMS 1969), now collectively called the Mansehra Granite (CALKINS et al. 1975). The Mansehra Granite is an S-type, peraluminous rock with flow-oriented alkali feldspar crystals as much as 15 cm long, and pinite pseudomorphs after cordierite/andalusite. Closely associated are medium-grained sodic muscovite-tourmaline granites and aplites, coarse-grained pegmatites, and less-abundant porphyries, soda aplites and albitites showing a progressive soda-enrichment trend (SHAMS & RAHMAN 1966). KEMPE (1983) included the sodic minor bodies of Mansehra into his alkaline igneous province that stretches to Loe Shilman at the Pakistan-Afghanistan border. Garnet amphibolites, epidiorites and dolerites of tholeiitic composition have intruded the granite complex (SHAMS & ZULFIQAR 1968).

The Swat Granite and granitic gneisses show trends similar to the Mansehra Granite, and similar features were observed in the granites of the Kaghan Valley and of Azad Kashmir (SHAMS 1983, TRELOAR 1989, WILLIAMS 1989). According to LEFORT et al. (1980), the Mansehra Granite yielded Rb/Sr whole-rock age of 516 ± 16 mio years, whereas the Swat Granite was dated at 515 mio years by the $^{40}Ar/^{39}Ar$ method (JAN et al. 1981), showing that both granite complexes belong to the regional belt of the Cambrian "Lesser Himalayan Cordierite Granites" of LEFORT et al. (1983), along with other granites of the Lesser Himalayas in Pakistan.

Thus, it is shown that an Early Proterozoic orogenic event affected the basement rocks of the Himalayas, followed by Early-Late Proterozoic sodic granite intrusions. After this event, the Late Proterozoic to Early Cambrian Hazara orogeny followed in the Himalayas. Silicic volcanism and plutonism accompanied this orogenic phase, 900 – 600 mio years ago. Subsequently, the Early Palaeozoic granites intruded into the basement rocks of the Indo-Pakistan Plate, accompanied by a phase of metamorphism 466 ± 2 mio years old. This can be compared with the Pan-African orogeny that had affected the Gondwanaland in general (BAIG et al. 1989).

4.114 Alkaline igneous province

West of the Indus River, alkaline igneous rocks cover an area of more than 1,000 km^2 extending to the Pakistan-Afghanistan Border (see Chapter 2.25). This was called the Peshawar plain alkaline igneous province by KEMPE (1983).

The Ambela granitic complex underlies the largest part of the alkaline province (about 900 km^2). It includes three groups of rocks: granites and alkali granites (about 70 % of the complex); quartz syenites, feldspathoidal syenites and related rocks, followed by dolerite dykes (MARTIN et al. 1962, SIDDIQUI et al. 1968, RAFIQ et al. 1989). The group of granites and alkali granites show a steady decrease in alkali ratio and simultaneous increase in silica. The syenites show a steady increase in alkali ratio and simultaneous decrease in silica. The trace-element plots show those to be within-Plate-granitoids (RAFIQ et al. 1989). Within the western part of the complex, carbonatite bodies (Naranji Kandao carbonatites of SIDDIQUI et al. 1967) form lenses and veins as much as 120 m long, composed of carbonates, feldspars, apatite, sphene and sodalite; the country rocks have been fenitized, also at Khungai, District Mardan (KHATTAK et al. 1984).

For the second group of rocks, the initial $^{87}Sr/^{86}Sr$ ratio of about 0.0704 (LEBAS et al. 1986) shows the involvement of mantle material, whereas the first group of rocks indicate crustal origin. SHAMS (1983) proposed crustal-uparching that produced anatectic melts (group I rocks), further charged with alkalis and volatiles from a mantle source to produce alkaline fluids (group II rocks). This phenomenon is well displayed at Shewa-Shahbaz Garhi, southwest of the Ambela complex and surrounded by alluvium of the Peshawar Plain. Here associated calc-alkaline and riebeckite-bearing alkaline porphyries exhibit a variation in magma composition in consonance with the fluctuating tectonic environment from compression to extension (CHAUDHRY & SHAMS 1983); KEMPE (1983) also proposed tectonic control for the origin of alkaline rocks of the Peshawar Plain.

Further west at Warsak, about 30 km north-northwest of Peshawar, sill-like bodies of alkaline microgranites and porphyritic alkaline granites, containing aegirine, riebeckite and astrophyllite, have been described (KEMPE 1973). The country rocks are Paleozoic greenschist facies metasediments containing metamorphosed mafic agglomerates and pillow lavas. KEMPE (1973) gave a K/Ar age of 41 mio years of a riebeckite from alkaline granite, while MALUSKI & MATTE (1984) reported an age range of 43.5 to 40 ± 5 mio years for garnetiferous microgranite. Notably, an accicular hornblende schist, representing a metamorphosed mafic tuff, was dated at 184 ± 17 mio years (KEMPE 1978), thus, defining an age-sequence of events in relation to the alkaline province rocks.

A complex of anastomosing dykes near the village of Sillai Patti, about 35 km west of Dargai, Malakand Agency, consists of carbonatites, peralkaline pyroxenites and fenitized granites. These dykes are 15 cm to 15 m thick, emplaced into Precambrian metasediments and granitic gneisses along a thrust fault (ASHRAF & CHAUDHRY 1977, BUTT et al. 1989). Similarly the sill-like carbonatite complex of Loe Shilman, Khyber Agency, is emplaced along a fault zone between Paleozoic schists and limestones in the north, and Precambrian slates and phyllites in the south. The complex is as much as 170 m wide and extends over 2 km; it continues into the Afghanistan territory (JAN et al. 1981, KEMPE 1983). Constituent rocks are amphibole-apatite carbonatites, dolomitic carbonatites and phlogopite-biotite carbonatites with metasomatized rocks at the contact. LEBAS et al. (1987) reported a K/Ar age of 31 ± 2 mio years for the carbonatite and 24 mio years for the deformed facies; the age of the deformed facies compares with the Sillai Patti carbonatite.

On the western bank of the Indus River, alkaline rocks are also known from the Tarbela damsite area, covering about 4 km^2. The complex is emplaced along a fault zone between Salkhala and Tanawal Formations, and consists of gabbroic rocks, followed by dolerites, melteigites, albitites, sodic granites, albite-carbonate rocks, and carbonatites as the youngest rocks. Widespread autometasomatism and alteration of country rocks were observed (SIDDIQUI 1973, JAN et al. 1981). KEMPE (1986) reported a K/Ar age of 350 ± 15 mio years of an amphibole albitite.

Soda aplites and albitites were also reported from the Mansehra Granite area (SHAMS 1983) that led KEMPE (1983) to extend the Peshawar Plain alkaline igneous province to the Mansehra rock complex in the east; HAMEEDULLAH et al. (1986), however, showed that the Malakand Granite, exposed on the Mardan-Swat road, is a much younger sodic granite of 23 ± 2 mio years ($^{40}Ar/^{39}Ar$) age (MALUSKI & MATTE 1984), and may not belong to the alkaline province.

4.115 Post Hercynian events

Following the Hercynian epeirogenic rifting-event, the crust of northern Pakistan experienced voluminous extrusions of the Permo-Carboniferous Panjal Volcanics (Panjal Formation; Fig. 3.2), now constituting the southeast-trending Panjal Range of Kashmir (WADIA 1928). The volcanics are as much as 1,400 m thick, and consist of basalt to basalt-andesite and tholeiitic to slightly alkaline composition. 60 chemical analyses revealed (in wt.%): SiO_2 = 47.24 – 57.76, Al_2O_3 = 12.45 – 16.89, CaO = 3.42 – 10.12, MgO = 2.24 – 6.98, Na_2O = 2.37 – 5.44 and K_2O = 0.27 – 3.14 (KHAN & ASHRAF 1989). Agglomeratic slates and tuffs are abundant in the lower parts of the flows. They exhibit pillow structure and are interbedded with chert and Triassic limestone, as well as closely associated Gondwana sediments (WADIA 1931, KHAN & ASHRAF 1989). BUTT et al. (1985) interpreted the chemical characteristics of the Panjal Volcanics as indicative of the oceanic crust that was created in the incipient phase of ocean development between the Hazara-Kashmir micro-continent in the north and the Gondwanaland in the south. Mafic dyke intrusions of unaltered to highly metamorphosed amphibolites are known from many parts of the Indo-Pakistan Plate but their age sequence is not yet clarified. They may have started nearly 2,000 ± 6 mio years ago, as for example in the case of the Besham amphibolites (BAIG et al. 1989). HUMAYUN (1986) used the chemical composition of amphibolites of the Swat Valley to propose that the mafic sheets, along with the associated arkosic sediments and marine carbonates and clastics, originated in a rift-related basin during Middle Paleozoic, accompanying the formation of the Palaeo-Tethys. An age of 262 ± mio years (KEMPE 1979) of a hornblende from a diorite body, belonging to the southern amphibolite belt of the Kohistan Arc Complex near Babusar, District Diamir, Northern Areas, possibly indicates that the diorite represents a plutonic equivalent of the Panjal Volcanics.

A particular type of metamorphism and ophiolitic magmatism was observed at the Main Mantle Thrust Zone, north of the Indo-Pakistan Plate, as the site of Plate subduction during Late Cretaceous. The MMT zone is a tectonic mélange of basalts, gabbros, peridotites, marine limestones, radiolarites, turbidites, and greenschist-blueschist facies rocks (SHAMS 1979, ARSHAD & SHAMS 1983). The blueschist mélange is composed of metavolcanics, phyllites, serpentinites, metagabbros, metadolerites, metagreywackes, metacherts and marbles. Limestone blocks containing Jurassic to

Middle Cretaceous fossils (KAZMER et al. 1983), as well as Eocene fossils (GUIRAUD 1986), are found embedded in the mélange; the blueschists yielded a K/Ar age of 84 ± 1.7 mio years (SHAMS 1979).

4.12 Kohistan Island Arc Complex

The Kohistan Island Arc sequence (see Fig. 2.24 and Chapter 2.253), exposed north of the MMT Zone, includes a complex of amphibolites, calc-alkaline intrusions, mafic-ultramafic complexes, volcanics and volcano-sedimentary rocks about 40 km thick. It is believed that this complex formed during the Mesozoic and was obducted onto the Indo-Pakistan Plate during the Late Cretaceous (BARD et al. 1980).

The amphibolites form a thick, continuous southern belt and a thin, discontinuous northern belt (CHAUDHRY et al. 1976), both having intrusive bodies of intermediate to ultramafic compositions. Banded, striped, massive and layered varieties are present, including those with structures derived from metamorphic differentiation. Chemical analyses of amphibolites from widely spaced outcrops show tholeiitic affinities, altough those derived by metasomatism of noritic gabbros are calc-alkaline (JAN 1980, RAFIQ et al. 1988). Para-amphibolites are not common, and are associated with meta-sedimentary formations, with which they have gradational contacts (CHAUDHRY et al. 1974). The intrusive bodies of granodiorites, diorites and hypersthene gabbros have typical calc-alkaline variations in chemical compositions and only slight iron-enrichment (MAJID 1979, 1980); this is notable in view of the tholeiitic composition of the amphibolites that were invaded by the calc-alkaline plutonic masses. On the other hand, the Utror Volcanics, interbedded with the Eocene Baraul Banda Slates, and composed of andesites, dacites, rhyolites, tuffs and agglomerates, show a typical calc-alkaline trend although with significant alkali-enrichment (MAJID 1979, 1980). Field relations show that the volcanic activity followed the intrusion of dioritic and related masses, but whether or not there is a genetic relation has not been clarified.

The Chilas mafic-ultramafic complex (see Chapter 2.253), represents one of the largest, exposed, mafic intrusions in the world. It consists predominantly of norites (Fig. 4.1) and gabbro-norites, with subordinate pyroxenites, anorthosites and quartz diorites containing labradorite/andesine plagioclase; intrusive into these rocks are small masses of dunite-peridotite-troctolite-anorthosite assemblages, characterized by bytownite/anorthite plagioclase (SHAMS 1975, JAN et al. 1984). Mineralogical features and chemical compositions show a genetic relationship among the various rocks, with a typical calc-alkaline trend of variation of an arc-related parent magma (HAMIDULLAH & JAN 1986) that crystallized at about 1,200 °C and at a depth of 20 – 25 km. As a result of the subduction process, tectonic folding and the increase of the thickness of the volcanic rocks piled above, the Chilas rock complex recrystallized under pyroxene granulite facies conditions (HAMIDULLAH & JAN 1984).

The Jijal mafic-ultramafic complex (see Chapter 2.253), exposed in the Indus River Valley in District Kohistan, N. W. F. P., is another rock mass having a geohistory comparable with the Chilas Complex, except that the Jijal Complex was metamorphosed at higher pt-conditions.

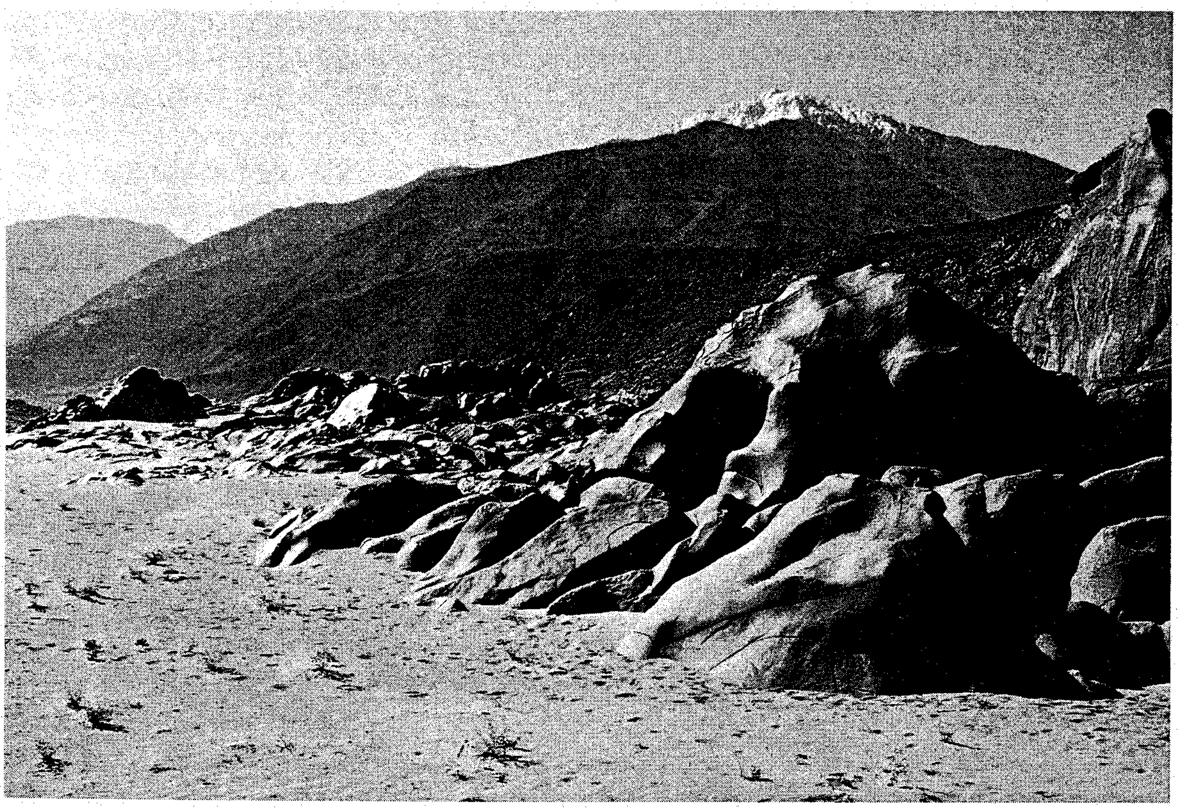


Fig. 4.1. Eolian corrasion of norite by sand-carrying wind; at road bank 2 km north of Chilas (Photo: F. BENDER).

The 2,700 km-long Kohistan Batholith is present on both sides of the Nanga Parbat Antiform. A segment of 280 km length and about 60 km width is exposed in the Kohistan Island Arc Complex. The rock compositions range from hornblendite to hornblende gabbro, from diorite to leucogranite, with dominance of dioritic compositions, and younger aplite, pegmatite and other minor rock bodies. PETTERSON et al. (1985) have distinguished three stages of intrusions: (1) early deformed gabbro-diorite and tonalite plutons, age 102 ± 12 mio years, representing one third of the batholith, formed in an island arc environment; (2) an undeformed suite of mafic dykes, gabbros, diorites, granodiorites and granites cutting structures of the early plutons, age 54 ± 4 mio years and 40 ± 6 mio years, formed in an Andean-type continental margin, and (3) the final stage aplite-pegmatite sheets, age 34 ± 14 mio years and 29 ± 8 mio years, formed by crustal melting (all ages by Rb/Sr whole-rock isochron method). The major elements follow a typical calc-alkaline trend. The low initial $^{87}Sr/^{86}Sr$ ratio of 0.7039 – 0.7052 suggests an ultimate source was the upper mantle, whereas some of the last-stage aplites-pegmatites were formed by partial fusion. A similar situation is known from the Ladakh Batholith, east of Nanga Parbat (SHARMA 1983).

The Kalam Group sequence (Fig. 3.6; see Chapter 3.32), including the Kalam, Kandia, Shatial and Thalichi metasedimentary formations of Jurassic to Cretaceous age, show metamorphism up to the garnet stage, including schists, phyllites and gneisses.

The Early Cretaceous Rakaposhi Volcanics (Fig. 3.6; see Chapter 3.33) represent primitive arc-type tholeiitic lavas, with folded pillows, succeeded by alkaline andesites and rhyolites (TAHIRKHELI 1982).

The Main Karakorum Thrust (MKT) Zone, separating the Eurasian and Indo-Pakistan Plates, contains andesites, basalts, serpentinites, ophi-calcite and less-abundant peridotites. These rocks are observed all along the zone between Khaplu in the east and Chitral in the west (DESIO 1963, ZANETTIN 1964, GANSSER 1980, TAHIRKHELI 1982, COWARD et al. 1982).

4.2 Karakorum Block

The Karakorum Block represents a rifted fragment of the Gondwanaland to which the Kohistan Island Arc Complex accreted during the Late Cretaceous. It consists of a metamorphic belt in the south, succeeded by the Karakorum Batholith, and a belt of sedimentary formations in the north (see Chapter 2.254). The metamorphic belt consists of metapelites, acidic gneisses and migmatites, and, in places, an ophiolitic mélange with ultramafic components. In the Hunza area, Barrovian-type metamorphism shows a northeastward increase in pt-conditions to a maximum of 669 °C and 5.5 kb (BROUGHTON et al. 1985), displaying an inverted sequence of metamorphic grades, ending with a thick migmatite zone adjoining the Karakorum Batholith. In the Baltoro-Biafo area, eastern Karakorum, the metamorphic conditions are 550 °C and 5.5 kb; the temperature increased to 625 °C near the Baltoro Pluton, causing migmatization and partial melting. Notably, the metamorphic grades show upward-decreasing pt conditions, in contrast to those in the Hunza area. Moreover, the rocks in the Baltoro area show contemporaneous regional metamorphism and genesis of the Baltoro Pluton whereas such a situation is not observed in the Hunza area (SEARLE et al. 1986, REX et al. 1988). Differences have been observed also in the plutonic components of the Karakorum Batholith in these two areas; whereas the Hunza area shows both I-type and S-type compositions (DEBON et al. 1986), the Baltoro area shows only the S-type composition (SEARLE et al. 1989). Thus, the Karakorum Batholith appears to be a composite rock body that may have different evolutionary and emplacement histories of its various components extending over at least 208 mio years, which is the age of the oldest pluton (Hushe Pluton) known so far (REX et al. 1988).

4.3 Eastern Hindukush

The eastern Hindukush igneous and metamorphic rocks are exposed north of the MKT in the District Chitral, N. W. F. P. (see Chapter 2.255). Slates and low-grade phyllitic slates have been described from this region (Chitral Slate (Fig. 3.6), Lun shales, Koghozi greenschist; DESIO 1975, PUDSEY et al. 1985). These metasediments are intruded by large and elongated granitic plutons, the Tirich Mir and Kafirstan Plutons, of biotite granodiorite to two-mica granite compositions. Garnet and tourmaline are common accessories but not much is known regarding their petrography and geochemistry. A specimen of the Tirich Mir Pluton yielded a Rb/Sr age of 115 ± 4 mio years (DESIO et al. 1964), which may apply to other plutons in this area as well.

4.4 Elements of the Indian Craton south of the Himalyas

Precambrian igneous and metamorphic rocks are exposed as outliers or are buried to the west of the Indian Craton in the Indus alluvial plain. They are discussed in Chapter 5.21. The Kirana Hills (HERON 1923, SHAH 1973) are composed of shales, thinly-bedded and cleaved slates, and conglomerates with clasts of carbonates, quartz and slates embedded in a matrix of sericite and hematite. These metasediments are profusely interlayered with acid and mafic volcanics and coarse-grained mafic intrusions of dolerites and gabbros. The acid volcanics are composed of rhyolites, rhyolite porphyries, rhyodacites, dacites, biotite andesites and glasses; ignimbrites and agglomerates represent explosive products. Notably, the acidic suite of rocks is potassic, in contrast to the sodic nature of the basalts. Rb/Sr whole-rock analyses revealed an age of 809 – 865 ± 20 mio years (DAVIES & CRAWFORD 1971), thus indicating a Late Proterozoic age of these low-grade metamorphosed rocks.

Rocks of the Precambrian Indian Craton are also exposed in the Nagar Parkar area, District Thar Parkar, Sindh Province (SHAH 1977, see Chapter 5.21). The grey granite is a semi-porphyritic rock with blue hornblende in pegmatite facies, whereas the pink granite is medium-grained, with pink alkali feldspar but without pegmatite facies; the pink granite is chilled against the grey granite. Dolerite dykes cut all other rock bodies, and as metabasites they show two distinct cleavages that indicate a Proterozoic metamorphic event (BUTT et al. 1989).

4.5 West Pakistan Foldbelt

The West Pakistan Foldbelt of Pakistan (see Chapters 2.23, 5.23) hosts the Bela, Muslimbagh, Zhob and Waziristan ophiolite complexes (Bela-Waziristan Ophiolite Zone; BANNERT et al. 1992; Fig. 4.2).

The Muslimbagh ophiolite complex, Zhob District, Baluchistan, is emplaced in a Cretaceous limestone-shale sequence with volcanics (Parh Group, Parh Limestone; Fig. 3.6), and is unconformably overlain by Eocene clastics so that the ophiolitic mass was emplaced during Paleocene or earliest Eocene (ALLEMAN 1979). In the northwest part of the complex, hornblende gneisses are found in the contact zone of the igneous mass, with large garnet crystals, but rapidly changing to biotite-bearing and then sericite-bearing schists. The latter grade into unmetamorphosed shales of the Parh Group. The intrusions consist mostly of serpentinised ultramafic rocks, such as saxonites, dunites and pyroxenites, along with minor bodies of gabbros and diorites. Dolerite dykes cut all other volcanics, and are found as normal dolerites, quartz dolerites and fine-grained dolerites (BILGRAMI 1964). SHAMS & SHAFEEQ (1976) described a suite of soda dolerites. Serpentinite is the matrix to the exotic blocks of radiolarites, marble, basalt and gabbro (ophiolitic melange). Another melange occurs at yet a lower stratigraphic/structural level, with shale as the matrix. Large-sized blocks of Jurassic platform carbonates are present as olistolites that slid downslope during deposition of the shale sediments (ABBAS & ZAKI 1979).

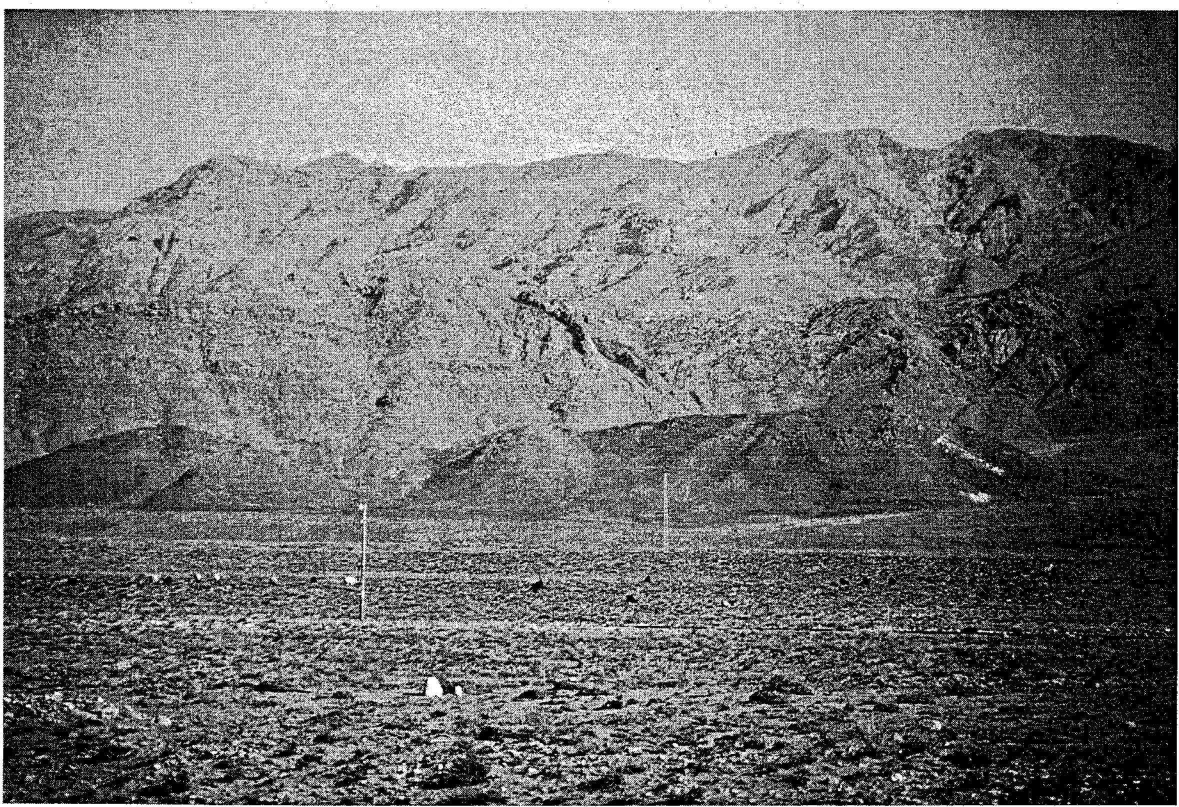


Fig. 4.2. Bordering the valley floor are dark bluish ophiolitic rocks of the Bela-Waziristan Ophiolite Zone. They are followed by lighter coloured Jurassic Loralai Limestone. Zhob Valley near Gwal (Baluchistan), view is to the east (Photo: D. BANNERT).

The association with Cretaceous volcanics is also a persistent feature of the other ophiolite complexes in the West Pakistan Foldbelt. These volcanics which consist of basalts to quartz andesites, were extruded in a marine environment (Fig. 4.3). The Bela volcanics form a belt about 140 km long and 24 km wide, exposed from near Ornach to Winder Nai, attaining a thickness of as much as 3,900 m. These volcanics are characterized by the dominance of pillow structure and widespread spilitization; radiolarian chert, jasper and silicified shale are associated (AHMAD & ABBAS 1979, DEJONG & SUBHANI 1979).

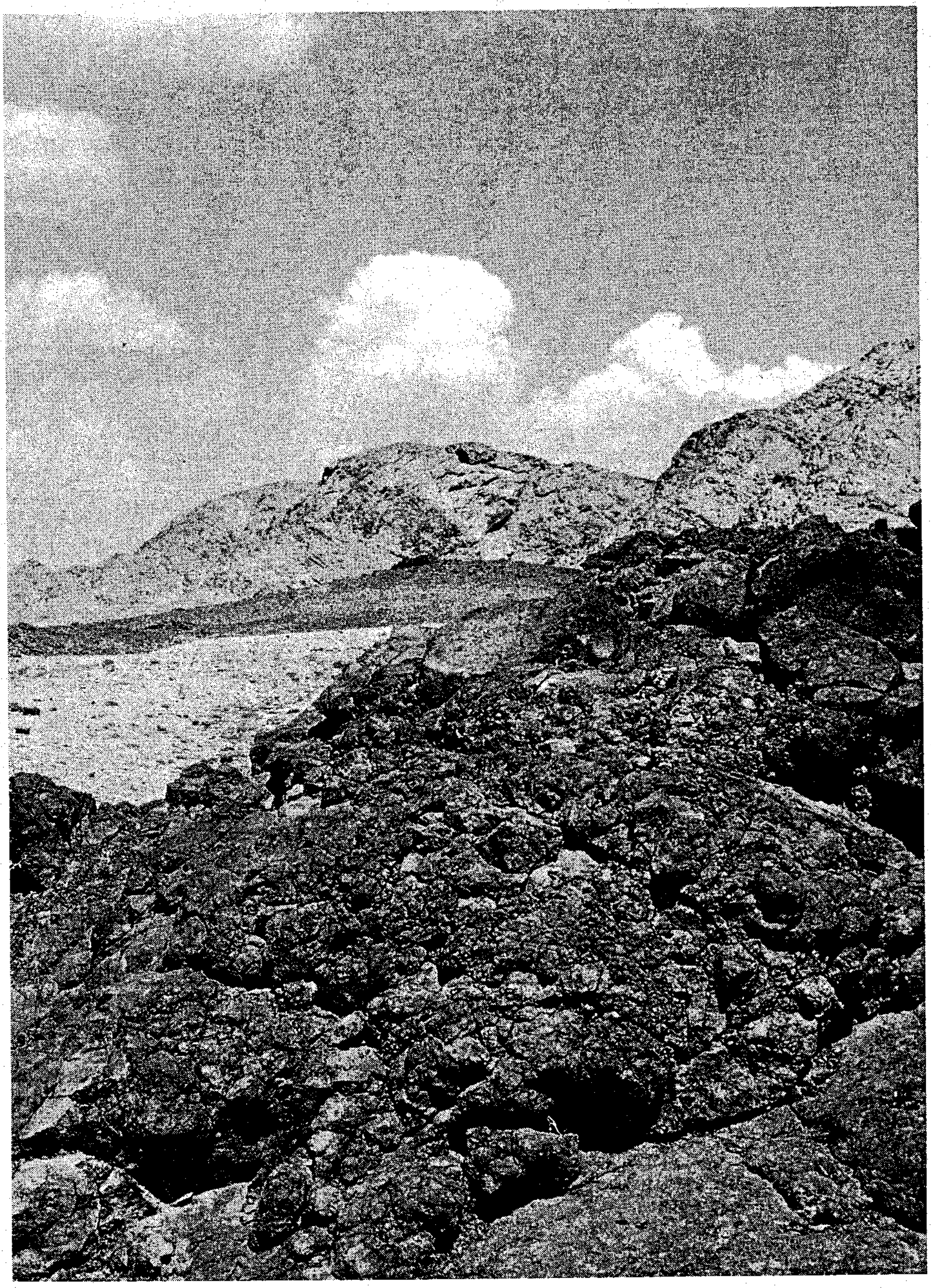


Fig. 4.3. Agglomerates assigned to seafloor volcanism of the Bela-Waziristan Ophiolite Zone are part of the western Khuzdar Block. In the background, Early Cretaceous limestone of the Goru Formation. Zawa Levy Post northwest of Khuzdar, Baluchistan (Photo: D. BANNERT).

4.6 Chagai-Ras Koh Volcanic Arc

The Chagai-Ras Koh Volcanic Arc (see Chapters 2.21, 5.24) is located in the extreme west of the Baluchistan Province. This area has been the scene of intensive igneous activity. Following the eruption of the Cretaceous Sinjrani Volcanics (Sinjrani Volcanic

Group; Fig. 3.6), a variety of igneous intrusions took place. The Chagai intrusions represent the upper part of a shallow batholith of dioritic to granitic composition (Hunting Survey Corp. 1960, SILLITOE & KHAN 1977). The Sinjrani Volcanics are extensively exposed in the north Chagai District, between Hamun-i-Lora to the east and Saindak to the west, south of the Pakistan-Afghanistan border. The rock sequence is 915 to 1,220 m thick, forming resistant hills, benches and terraces. The rocks are in layers as much as 15 m thick containing unsorted boulders and fragments of red and green porphyritic basalt and quartz andesite, and thin beds of multi-coloured ash and tuff. Porphyritic lavas contain phenocrysts of augite, hornblende and feldspar, and, locally, of olivine and hypersthene. Associated tuffaceous shales and green sandstone are believed to have been derived from local volcanic material under sub-marine conditions. Lenticular masses of calcareous shales and limestones are commonly associated (Hunting Survey Corp. 1960, AHMAD et al. 1972). Volcanics, tuffs and lavas are also associated with the Maestrichtian Humai Formation (Fig. 3.8), the Paleocene Rakhshani Volcanics (Rakshani Formation), the Eocene-Oligocene Saindak Formation (Fig. 3.8) and the Oligocene Amalaf Formation (Fig. 3.8).

The latest igneous activity in the Chagai-Ras Koh Volcanic Arc is in the Koh-i-Sultan area (Fig. 7.24). The bulk of the rocks are agglomerates, tuffs and subordinate lavas. In this area of major volcanic activity from Cretaceous through Recent, sulphur was deposited; the so-called onyx marble is considered to have been formed by hot water springs during the solfataric phase of volcanism.

4.7 Additional igneous rocks

Volcanic rocks constitute an important part of the Middle Paleocene Bara Formation (Fig. 3.8) in the Laki Range. The Formation consists of dominant sandstones, with lesser shales and volcanics, the latter being more a volcanic debris (SHAH 1977).

The Late Proterozoic to Early Cambrian Salt Range Formation (Fig. 3.2) contains a 6 m thick layer of purple to green Khewraite rock with a groundmass of orthoclase and altered needles of augite (see Chapter 3.21; MOSEBACH 1956). The molasse sequences of the Potwar Plateau carry some sandstone layers with thin volcanic ash beds that are now highly altered.

5. Tectonics and structure

The complexity of tectonics and structure in Pakistan warrants a discussion of the regional setting of these features (Chapter 5.1), and a description of the Tectonic zones (Chapter 5.2). "Tectonic zones" are here understood as areas that are dominated by a characteristic tectonic and structural setting and development. It is therefore unavoidable that parts of the description are repeated as compared with Chapter 2 (Geological framework).

5.1 Plate boundaries and regional fabric

(FRIEDRICH K. BENDER)

The boundary between the Eurasian Plate and parts of the Gondwana Continent, including the Indo-Pakistan Plate, is marked by a zone of intermittend ophiolites. This boundary has a latitudinal trend along the Herat-Hindu Kush Fault Zone in Afghanistan and turns steeply to the NNE-NE-E-SE in the Pamir and Karakorum, before it strikes again in the latitudinal direction in the Tibetan region (Figs. 5.1, 2.3, 2.4).

According to POWELL (1979), the abrupt bend to the north involving the Himalayan Arc, was caused by the impingement of very large, sinistral, transcurrent faults. Along these the Indo-Pakistan Plate moved northward for about 1,000 km. The eastern margin of the Indo-Pakistan Plate, in Myanma (Burma), has similar longitudinal, but dextral features (BENDER 1983).

Originally, the Tethys Ocean occupied the region along the southern margin of the Eurasian Plate. As the Indo-Pakistan Plate moved northward, the Tethys Ocean closed and intervening microplates such as the China-Turan and Tarim Plates, were attached to the Eurasian Plate, along with sedimentary and metamorphic sequences of the Indo-Pakistan Plate (Figs. 6.3 through 6.5; Fig. 6.9).

The present western extension of the Gondwana land-mass is obscured in Baluchistan and in the West Pakistan Foldbelt and might consist of the terranes of the Afghan Kabul Blocks ("AG" in Fig. 6.3). The Kohistan Island Arc rock complex (see Chapter 2.253; Fig. 2.24) of the Neo-Tethys was thrust over rocks of the Indo-Pakistan Plate and welded together with the Karakorum microplate along the Main Karakorum Thrust (MKT; or Northern Suture) and the Main Mantle Thrust (MMT; TAHIRKHELI et al.

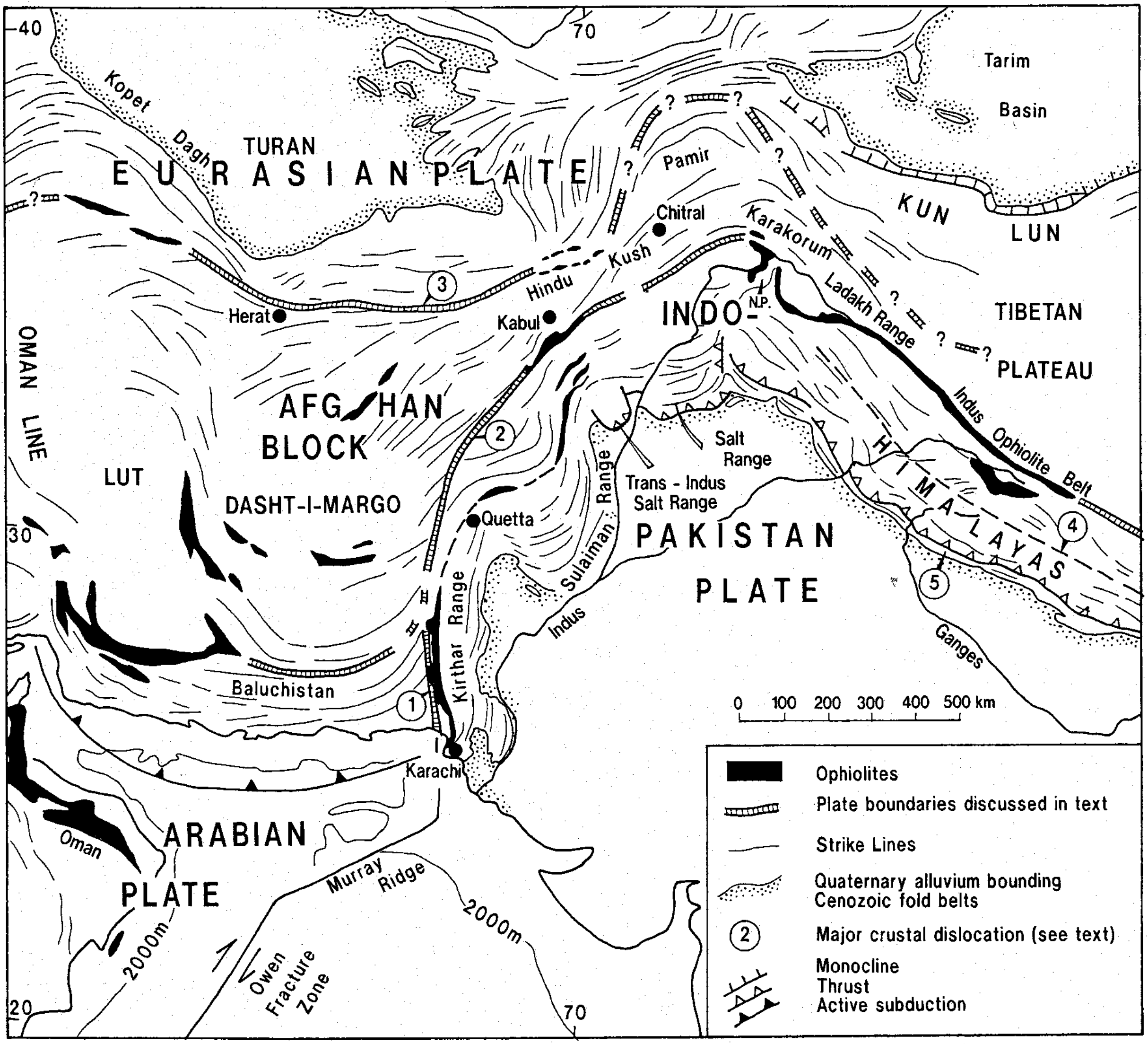


Fig. 5.1. Plate boundaries and ophiolites. Sketch map of Pakistan and adjacent regions showing generalized strike lines and the limits of the Cenozoic fold belts rimmed by Quaternary alluvium: (1) Ornach-Nal Fault; (2) Chaman Fault; (3) Herat-Hindukush Fault Zone; (4) Himalayan Central Crystalline Axis; (5) Himalayan Main Boundary Thrust (MBT). N. P. = Nanga Parbat (compiled and modified after POWELL 1979 and QUITTMEYER 1979).

1979, COWARD et al. 1982, SEARLE et al. 1987). TAPPONIER et al. (1981) and BUTLER et al. (1988) considered the Karakorum microplate as to be part of Gondwana (Fig. 2.4).

In the Pakistan-Himalayas, the Indo-Pakistan/Eurasia suture zone is represented by the Main Mantle Thrust (MMT; Fig. 2.4). It forms, together with the Main Karakorum Thrust, probably the earliest (Cretaceous – Early Tertiary) suturing during collision in this region. In the Kohistan Island Arc Complex, the thrust apparently originated as a break-up structure in the hanging-wall of the pre-collisional (oceanic) subduction zone, as observed by BUTLER et al. (1988) in the NNE trending upright antiform of the Nanga Parbat Syntaxis (Fig. 2.4). Another, but much smaller, north trending antiform appears further west along the MMT, in the area of Jijal, west of 73° longitude (Fig. 2.4).

A major shear zone carried here the Jijal Complex and the Kohistan Island Arc Complex as detached nappes southward over quartz-feldspar gneisses of the Indo-Pakistan Plate (COWARD et al. 1982).

The region south of the MMT is occupied by rocks of the Indo-Pakistan Plate. Here, several additional thrusts appear, including the Main Boundary Thrust (MBT) to the south. This bundle of thrusts follows, in general like the MMT, the NE-east-SE directions of the Himalayas (Fig. 2.3), with one pronounced exception, the Hazara Syntaxis (Fig. 2.4; WADIA 1931, CRAWFORD 1974, CALKINS et al. 1975). With this syntaxial bend, the structural trends curve through nearly 90° to the north from the Himalayan Arc. POWELL (1979) considered the Hazara Syntaxis to be the result of the interaction of three independently moving tectonic elements: The Himalayas, the Indo-Pakistan Shield, and the Salt Range.

The MBT marks the physiographic south border of the Himalayas in Pakistan. West of the Jhelum Re-entrant, it splits into several, overlapping thrusts. South of it, partly underneath the alluvial plain of the northern Punjab, the sedimentary sequences are strongly deformed as well, associated with a number of additional thrusts. The structural trends clearly follow the configuration of the MBT, including the Hazara Syntaxis, which widens to the south; so does the Salt Range Thrust, corresponding to the Main Frontal Thrust (MFT) further south, which separate the folded and faulted region of northern Punjab with the Kohat-Potwar Plateau from the less deformed Punjab Foreland in the south (Fig. 2.4).

All elements of the tectonic framework of the Himalayas turn southwest and south into the West Pakistan Foldbelt (see Chapter 2.23). The deformation of rock sequences between the Eurasian Plate in the north and the Indo-Pakistan Plate in the south was accompanied by the development of sinistral strike-slip lineaments along the western margin of the Indo-Pakistan Plate, associated with detachment tectonics in the segments between both plates (SAWAR & DE JONG 1979, BANNERT et al. 1992).

As viewed from south to north in the West Pakistan Foldbelt (Figs. 5.7, 5.8, 5.9, geol. maps), the Kirthar-Sulaiman Ranges extend northward from the southern Khuzdar Block, bend eastward around the Quetta Syntaxis (WADIA 1953), continue in the Loralai Lobe (Hunting Survey Corp. 1960), and finally coalesce in the northeast with the Transindus Ranges and Salt Ranges of Kohat and Potwar (Fig. 2.2).

In the Gondwana sediments (Cambrian to Permo-Triassic) of the Afghan Block, TAPPONIER et al. (1981) observed strong tangential deformation which occurred during the Triassic. Rocks of the Mesozoic Palaeo-Tethys appear at the Panjao Suture (Fig. 2.3) with ophiolitic mélanges/Permo-Triassic limestones, and Upper Triassic to Jurassic flysch. The emplacement of the ophiolitic rocks indicates the closure of the Palaeo-Tethys. The accretion of the Afghan Block to the Eurasian Plate occurred between Late Jurassic and Early Cretaceous, as shown by the Barremian and Aptian epicontinental series lying unconformably over highly deformed flysch sequences and mélanges (TAPPONIER et al. 1981).

Neo-Tethyan rocks are found east of the Afghan Block along two zones of ophiolites: The Bela-Waziristan Zone, apparently extending into the Afghan Khost Ophiolite Complex (TAPPONIER et al. 1981), and the Usman Fault-Chaman Fault Ophiolitic Zone. The Usman part of this zone is located south of the Dasht-i-Margo Block, a continental fragment of Gondwana origin (LAWRENCE & YEATS 1979), which belongs to the southern Afghan Block. The Chaman Fault-portion of the ophiolitic zone separates the Afghan Block in the west from the Kabul Block in the east (Fig. 2.2; TAPPONIER et al. 1981). TAPPONIER et al. (1981) considered the age of the emplacement of the ophiolitic mélange as of pre-Late Paleocene age because of the presence of exotic Maestrichtian limestone. This corresponds to the emplacement age of the Muslimbagh and Bela ophiolites (ALLEMANN 1979).

South and southeast of the Afghan and Kabul Blocks a flysch basin developed towards the end of Cretaceous times (ARTHURTON et al. 1982). It received flysch sediments till the end of Miocene times. In the Makran area, the flysch sedimentation

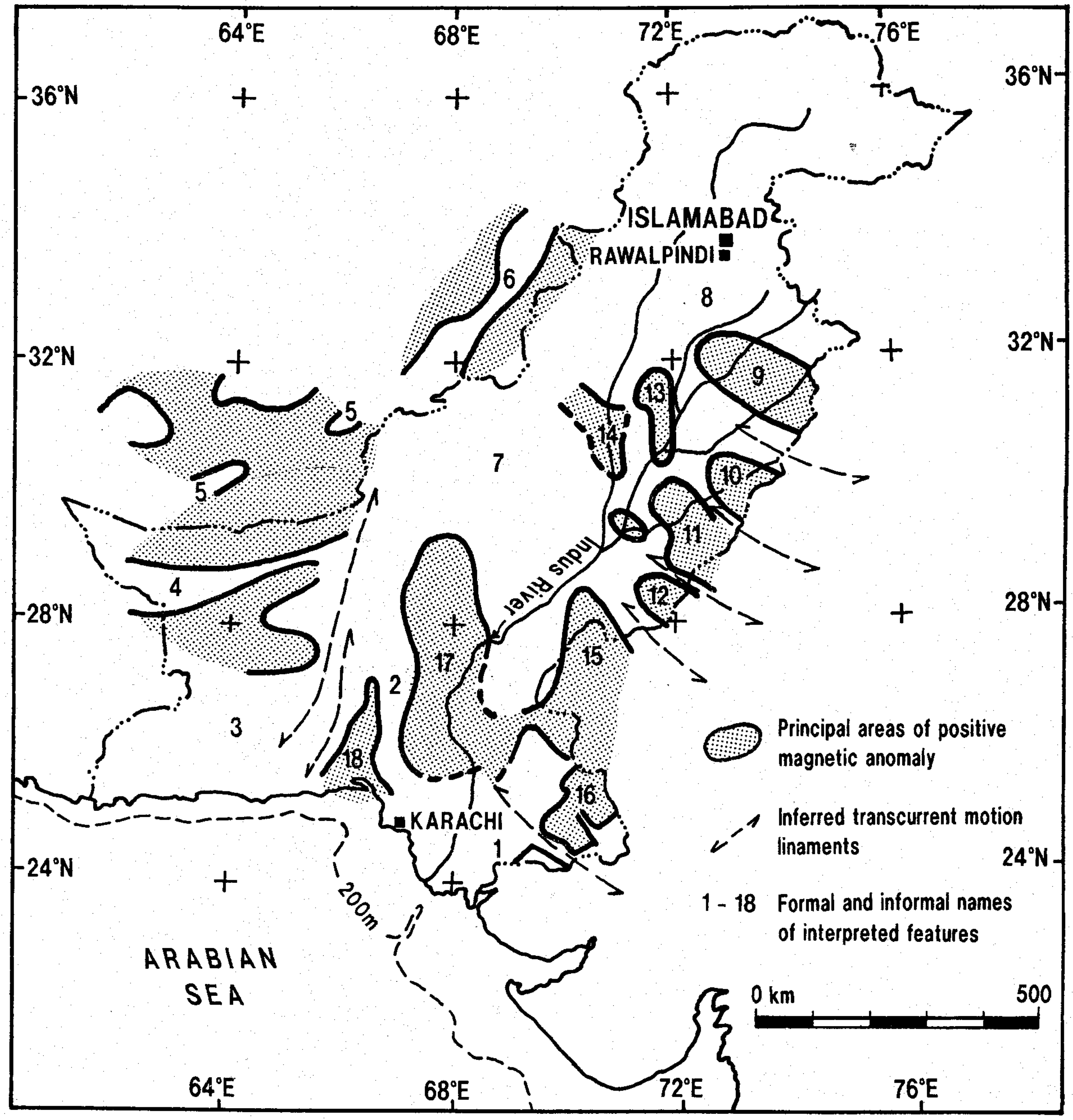

64°E
68°E
72°E
76°E
36°N
32°N
28°N
24°N
ISLAMABAD
RAWALPINDI
KARACHI
Indus River
200m
ARABIAN SEA
1
2
3
4
5
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Principal areas of positive magnetic anomaly
Inferred transcurrent motion linaments
1 - 18 Formal and informal names of interpreted features
0 km
500
64°E
68°E
72°E
76°E

Fig. 5.2. Principal features of magnetic anomalies (after DOLAN et al. 1987, fig. 21).

continued above the subduction zone beneath which the Arabian Plate is consumed (Fig. 5.1; WHITE & KLITGORD 1976). The flysch basin, the Makran-Kohjak-Pishin Flysch Trough (Fig. 2.5) of BANNERT (1990), was affected by different styles of deformation during collision of the Indo-Pakistan Plate with the Afghan and Kabul Blocks. The middle section of the basin (Khojak flysch) was bent and stretched in north-south direction when the sinistral transcurrent Chaman Fault in the west and the Ghazaband Fault in the east facilitated the northward indention of the Indo-Pakistan Plate into the Eurasian Plate. During progress of this indention, the Khojak flysch belt with the adjacent part of the Bela-Waziristan Ophiolite Zone to the east of it, rotated in an anticlockwise manner, and numerous longitudinal strike-slip faults dissected the flysch sequences. BANNERT (1990) identified on satellite images frequent left-lateral offsets of magnitudes of about 20 km each, which add up to an estimated left-lateral offset of 200 km - 400 km (LAWRENCE & YEATS 1979, TAPPONIER et al. 1981).

Plate boundaries and regional fabric south of the Makran coast are characterised by an active subduction zone along the Gulf of Oman, and by the Murray Ridge Owen Fracture Zone (Fig. 5.1).

The latitudinal Gulf-of-Oman subduction represents the oceanic segment of the Arabian Plate. Thrusting continues northwest into the zone of continental collision in front of the Zagros Mountains. Along the Gulf of Oman and parallel to the Makran coast, oceanic portions of the Arabic Plate were subducted northwards during most of the Cenozoic, with a present relative motion of about 5 cm/year (WHITE 1977, JACOB & QUITTMEYER 1979). According to these authors, the Makran region forms a nearly complete trench-arc system with an accretionary prism of 300 km width.

Along the WSW trending Murray Ridge in the Arabian Sea, right-lateral strike-slip faults and rifting are developed, which turn to the southwest into the Owen Fracture Zone. The latter displays active transform faults with right-lateral motions between the Arabian and Indo-Pakistan Plates.

The tectonic framework of the eastern Indus Basin is dominated by the western margin of competent rocks of the Precambrian Indian Shield. Shield elements reach far to the west into the Indus Basin, probably along latitudinally trending transform faults. Since Cambrian times, these partly exposed elements influenced formation and configuration of individual basins and swells at the eastern margin of the large Indus Basin (Fig. 5.2).

5.2 Tectonic zones

Regions or areas of characteristic tectonic and structural setting and development (tectonic zones) are:

(1) Shield elements of the Precambrian Indian Craton that extend westward into Pakistan (Chapter 5.21)
(2) the Indus Basin that extends southward from the Main Boundary Thrust to the offshore area south of Karachi (Chapter 5.22)
(3) the West Pakistan Foldbelt (Chapter 5.23)
(4) the Chagai-Ras Koh Volcanic Arc (Chapter 5.24)
(5) the Hindukush-Pamir-Karakorum Himalaya region.

The region (5) comprises various tectonic zones the discussion of which was incorporated in Chapter 2 (Geological framework).

5.21 Shield elements and buried ridges

(FAIZ AHMAD SHAMS)

Precambrian rocks belonging to the Indian Shield are exposed in the central part of the Punjab Province and in the southeastern corner of the Sindh Province. These rocks were the source of clastic material for younger sedimentary formations.

Magnetic and gravity anomalies indicate the existence of further but completely buried shield elements in Pakistan, five of them connected with the Indian Craton. These elements trend northwest, like those exposed in the Punjab and in the Sindh Provinces, and are possibly separated from each other by trans-current motions (Fig. 5.2).

The shield elements in the Punjab are lowlying barren hills: Kirana (31° 55'N; 72° 43'E), Chiniot (31° 43'N; 72° 58'E), Sangla (31° 42'N; 73° 22'E) and Shahkot (31° 34'N; 73° 28'E). They appear abruptly as isolated outliers in the alluvial plain of the Indus Basin. The sedimentary sequence of the Kirana Group (SHAH 1973, ALAM 1983) is composed of grey to greenish-grey shales and slates that dominate in the eastern hills, and coarse to fine-grained reddish quartzites that dominate in the western hills. Conglomerates with quartzitic or carbonatic pebbles are also present. Inter-layered with the sediments are thick beds of potassic rhyolites, sodic basalts and tuffs, and the sediments are intruded by dolerites and gabbros. The Precambrian age of the Kirana Group was determined by DAVIES & CRAWFORD (1971) as 809–865 ± 20 mio years (K/Ar), indicating that these rocks can not be correlated with the Malani rhyolite of Rajasthan, India, as was proposed by HERON (1923).

The exposed Precambrian rocks in Sindh are located at Nagar Parkar (24° 21'N; 70° 46'E) in the Thar Parkar District. The rocks consist of pink and grey granites, with dolerite and gabbro intrusions, named as Nagar Igneous Complex by KAZMI (1973). The oldest rocks are dominantly gneissic metabasites (BUTT et al. 1989).

Gravity surveys (FARAH et al. 1977) showed that the Kirana outliers are the surface projections of a buried ridge (Sargodha Ridge), extending northwestward from the Indian Shield. Its southeastern extension is believed to join the Hissar Ridge, west of Delhi, India. A similar situation is accepted for the Nagar Parkar outliers as portions of a buried ridge that extends in northwest direction. Structurally, Kirana and Nagar Parkar outcrops are considered as horst-like bodies with steeply faulted contacts, nearly vertical strata and variable strike directions. Notably, Sargodha Ridge outliers show divergent northeast trend in the eastern hills and northwest trend in the western hills, the former conformable to the Aravalli Range in the northwestern India and the latter conformable to the Himalayan Range in the north (GANSSER 1964). Considering these and other distinct features, AHMAD (1964) recognized these ridges as belonging to a system of "swells" in the Precambrian basement that were responsible for the existence of various sedimentary basins. Magnetic surveys have elaborated this concept in the Pakistan part of the Indian Shield (Fig. 5.2).

The Sargodha Ridge is seismically active and belongs to the Punjab seismic zone of Seeber & Armbruster (1979) that includes the Hissar Ridge and extends to Delhi, India (Menke & Jacobs 1976). Exploratory wells drilled at Kundian (31° 00'N; 74° 17'E) and Karampur (29° 53'N; 72° 21'E), north and south of the Sargodha Ridge respectively, show a complete stratigraphic similarity (Fig. 5.3) and prove post-sedimentation emplacement by tectonism of the ridge. Yeats & Lawrence (1984) explained the tectonic configuration of the Sargodha Ridge as an outer "swell" that had risen as a result of bending-moment stresses generated by loading of the Indian Shield by the Himalayan thrusts (Fig. 5.4). Earlier, LeFort (1975) had suggested that tectonic

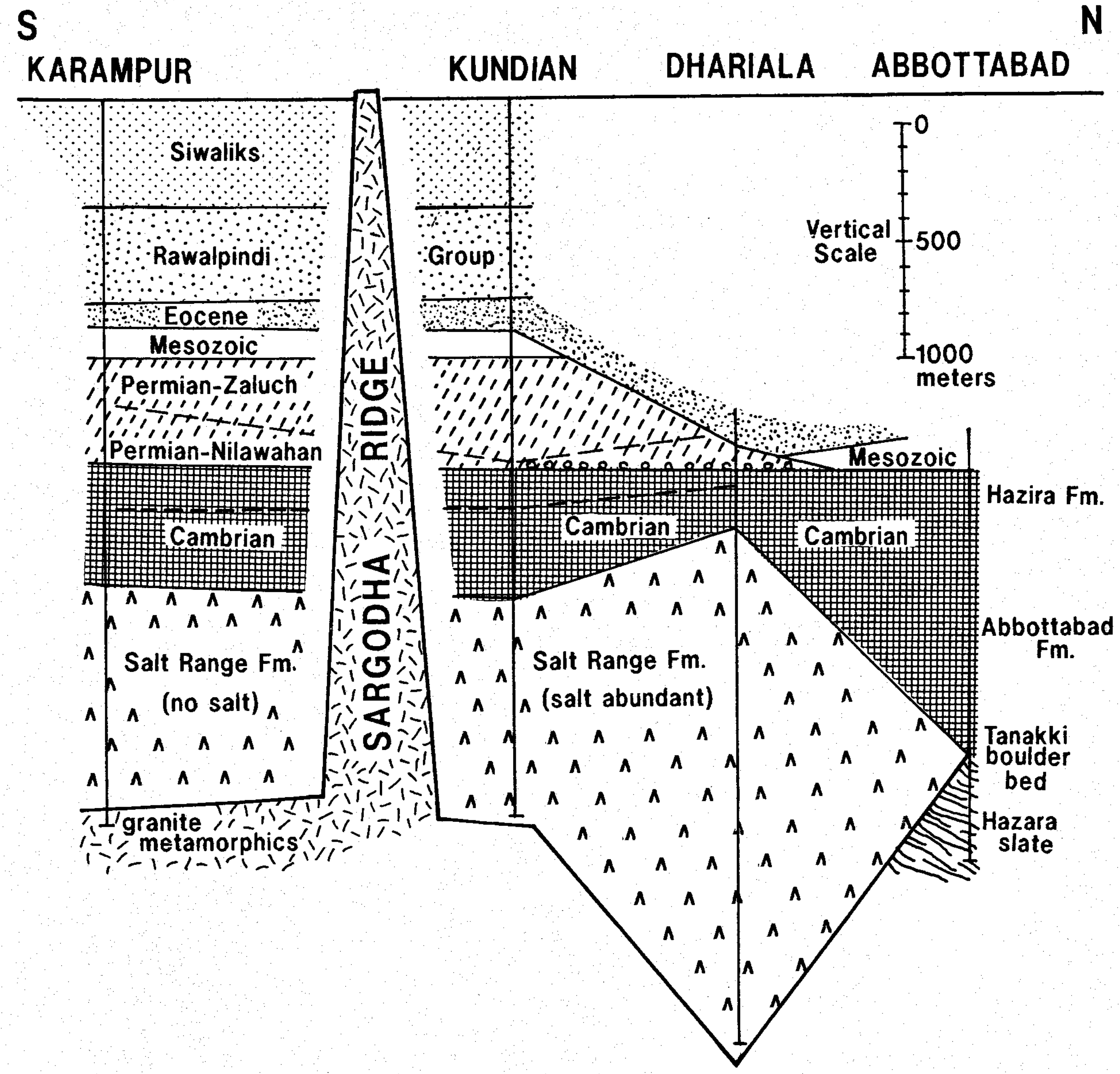


Fig. 5.3. Stratigraphic correlation across the Sargodha Ridge from the Punjab Plain in the south to the Hazara area in the north. Length about 550 km (after Yeats & Lawrence 1984).

activity along the Sargodha Ridge represents a new thrust fault forming an incipient subduction zone after the buoyancy constraints did not allow further subduction within the Himalayas. According to ARMBRUSTER et al. (1978), recent seismicity within the Himalayas is associated with a frontal zone of deformation. This zone parallels the Hazara Syntaxis and should correspond to the Main Boundary Thrust (MBT) that became active after cessation of motions along the Main Central Thrust (MCT) at the base of the Higher Himalayas (LEFORT 1975, MATTAUER 1975). If the structural motion along the Sargodha Ridge is accepted as the formation of a new thrust fault, an incipient MCT, then a southward progradation of subduction zones will have to be accepted. This will have far reaching implications, such as lifting of the linear belt between the proposed Sargodha Ridge Thrust (SRT) and the MBT.

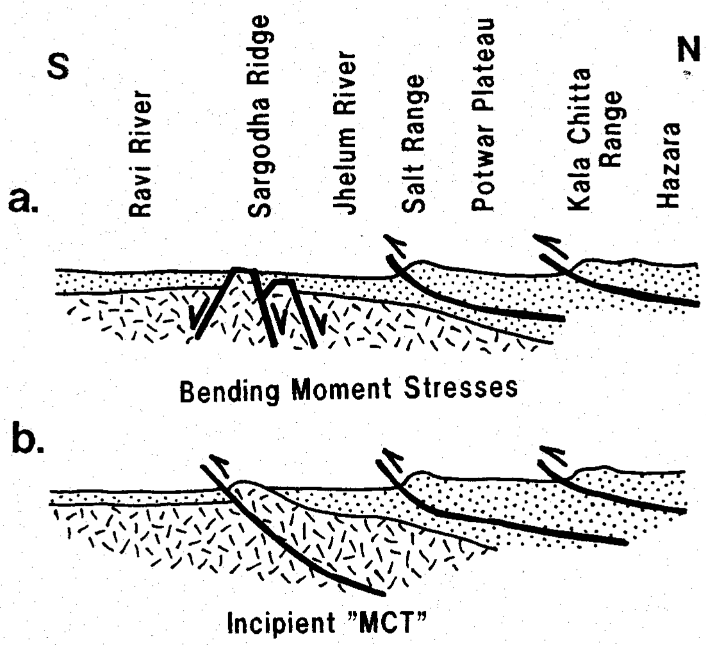


Fig. 5.4. Diagrammatic section across the foreland thrust belt of the Pakistan Himalayas, illustrating two possible origins of the Sargodha Ridge (after YEATS & LAWRENCE 1984).

In addition to the ridges of the continental crust, those of oceanic origin are also recognized. One such ridge is believed to exist in the linear core of the Ras Koh Range, west of Quetta (30° 12'N; 67° 01'E), Baluchistan Province. The constituent rocks are composed of serpentinized ultramafics (Bunap intrusions of Eocene and younger age). The physical barrier formed by this ridge is shown by the contrast of sedimentary facies across the Ras Koh Range: arenaceous facies in the north, and calcareous facies in the south of the buried ridge (Hunting Survey Corp. 1960, BAKR 1963). The so-called Dargai klippe of TAHIRKHELI et al. (1979), N W F P, and its extensions into the Mohmand Agency (RAFIQ 1984) could be an exposed ridge also. It is a steep to vertical, north dipping, thrust-faulted linear body that is dominantly composed of dunites, peridotites, serpentinites and basic rocks with chromite lenses.

5.22 Indus Basin

(FRIEDRICH K. BENDER)

Tectonic and structural setting of the Indus Basin is discussed in some detail in Chapter 7.1 (Hydrocarbons) and in Chapter 2.24, because this is the most important region

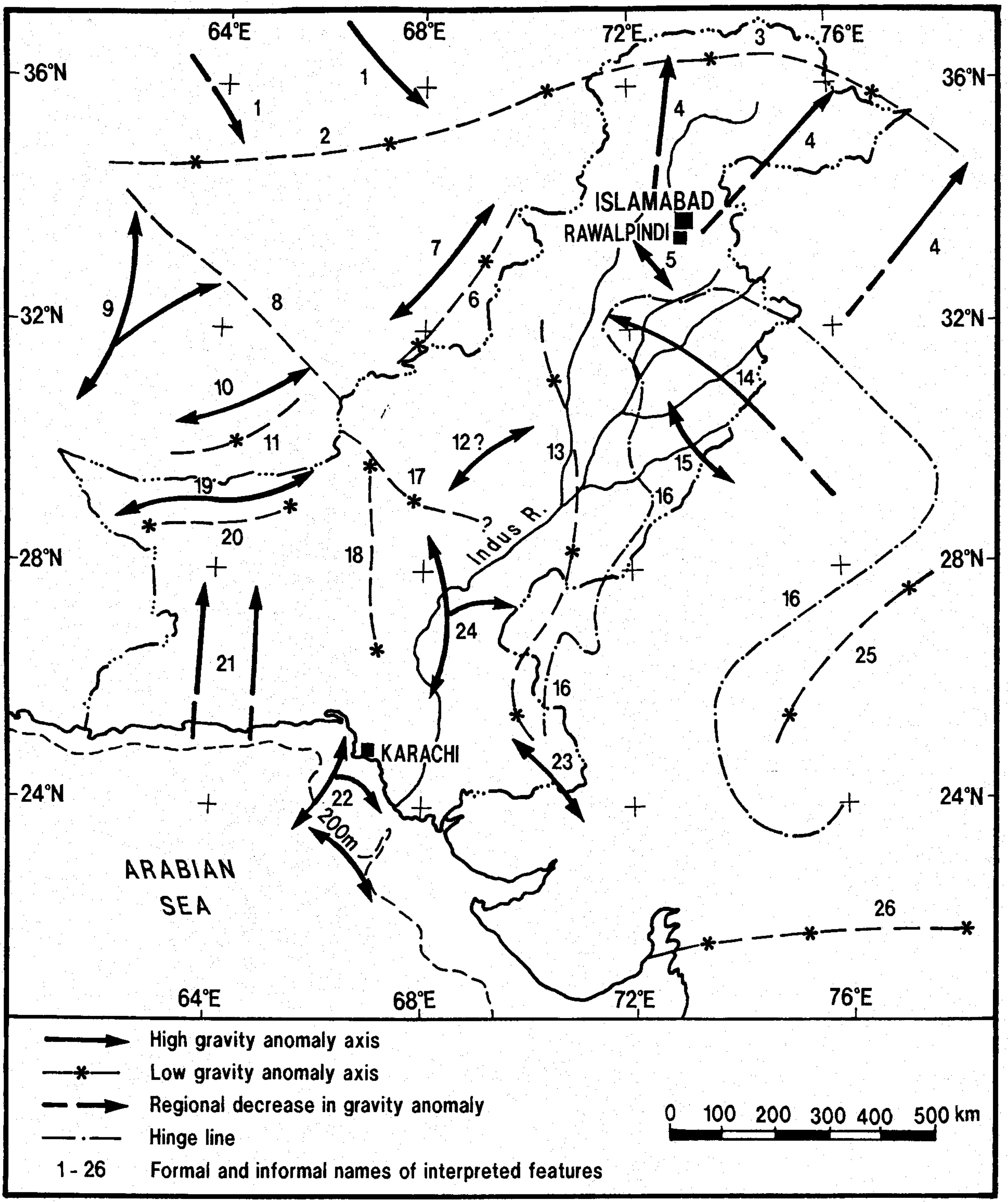


Fig. 5.5.

for hydrocarbon production and potential in Pakistan. In the following, tectonism and structure are therefore only summarized.

The Basin might be subdivided in four parts with different sedimentary facies, and partly different tectonism and structure. As viewed from north to south these are

(1) Kohat-Potwar Foredeep, Upper Indus Basin (see Chapter 7.12): This part consists of a fold and thrust belt south of the Main Boundary Thrust, associated with, and terminated to the west and the east, by longitudinal transcurrent fault systems (Fig. 7.2);

(2) northern Lower Indus Basin and Sulaiman Foredeep (see Chapter 7.13): This part of the Basin (Fig. 7.5) is structurally dominated by rifting during the Triassic, by the oblique collision of the Indo-Pakistan Plate with the Afghan Block during Late Cretaceous through Palaeogene, and post-collisional deformation during Neogene through Quaternary;

(3) central Lower Indus Basin and Kirthar Foredeep (see Chapter 7.14): In general, this part is structurally comparable with (2), but different from (2) on grounds of facies distribution in Mesozoic sediments;

(4) southern Lower Indus Basin and offshore area (see Chapter 7.15): Again, tectonism and structure are comparable with (3) and (2), and the individual structures are associated with Triassic rifting, Late Cretaceous-Palaeogene collisional events, and Neogene-Quaternary post-collisional deformation. Various thick sediment accumulations showing distinct deposition centers developed during the Cenozoic, and the facies distribution of Mesozoic and Cenozoic sediments differs from (3).

DOLAN et al. (1987) gathered gravity data from various sources, and compiled the principal Buguer anomalies on a regional basis (Fig. 5.5). Together with magnetic anomalies (Fig. 5.2), an interpretation is possible to locate the major structures in the Indus Basin beneath the thick cover of unconsolidated Quaternary sediments.

Fig. 5.5. Buguer gravity principal anomalies (after DOLAN et al. 1987, fig. 22). Formal and informal names of interpreted features:

1 – Karam-Taajik Platform
2 – Central Afghanistan Low
3 – Karakoram Low
4 – North Punjab Gradient
5 – Campbellpore High
6 – Katawaz Trough
7 – Kabul High
8 – Herat Kandahar Trend
9 – Farah High
10 – Kandahar High
11 – Registan Low
12 – Zhob High
13 – Indus Basin Low
14 – Sargodha Ridge
15 – Sahiwal High
16 – Jaisalmer Shelf Edge
17 – ? Loralai Low
18 – Kirthar Range Low
19 – Chagai Hills High
20 – Dalbandin Trough
21 – Makran Coast Gradient
22 – Indus Delta Highs
23 – Nagar Parkar High
24 – Jacobabad High
25 – Vindhyan Basin Low
26 – Narmada Rift Low

5.23 The West Pakistan Foldbelt

(DIETRICH BANNERT)

The West Pakistan Foldbelt (Figs. 5.6, fold-out Sheet 1; 5.7, fold-out Sheet 2; 5.8, fold-out Sheet 3; geol. maps) is the sedimentary cover of the Indo-Pakistan Plate which was folded during the continent-to-continent collision with the Eurasian Plate. STOECKLIN (1977) called this area the Kirthar-Sulaiman mountain belt. He and all later students of the area regarded the fold belt as a continuous range of folds, that bent around the Quetta Syntaxis (WADIA 1953) and continue in the Sulaiman Arc (SAWAR & DEJONG 1979). BANNERT et al. (1992) assumed that the basement of the continental Indo-Pakistan Plate was segmented into three different blocks during the collision of the Indo-Pakistan Plate with the Eurasian Plate. They identified the **Khuzdar Block** (Fig. 5.9, fold-out), the **Sulaiman Block**, and the **Hazara Block**. The Khuzdar Block and Sulaiman Block are included in the West Pakistan Fold Belt. The style of deformation in the sedimentary cover above the three blocks is different for each block. Three basement faults separate these basement blocks from each other and from the central part of the Indo-Pakistan Plate. The Khuzdar Block and the Sulaiman Block are separated by the Kirthar Basement Fault, the Sulaimán Block and the Hazara Block by the Sulaiman Basement Fault, and the Hazara Block and the main body of the Indo-Pakistan Plate to the east are separated by the Jhelum Basement Fault (Fig. 2.2). WADIA (1953) had already postulated a spur of the Indian Shield in that area. Epicenters of modern earthquakes (QUITTMEYER et al. 1979) indicate the presence of tectonically active ruptures which can be associated with the Kirthar Basement Fault.

5.231 Khuzdar Block

The Khuzdar Block (Fig. 5.10, fold-out) underwent a complicated tectonic history during the collision of the Indo-Pakistan Plate with the Afghan Block. When the Indo-Pakistan Plate approached the Afghan Block at the end of Cretaceous a considerable amount of Tethyan sea-floor had already been consumed under the northern subduction zone which extended from the Indus-Tsangpo Suture Zone in the east, via the south of the Kohistan Arc and then towards the Kabul Block and the Afghan Block (Figs. 2.3, 2.4). The Khuzdar Block was the leading edge that collided first with the Afghan Block (SAWAR & DEJONG 1984). This happened during the Late Maestrichtian or, at the latest, during the Paleocene (ALLEMANN 1979), when the obduction of the Bela-, Muslimbagh-, Zhob-, and Waziristan ophiolites took place (Fig. 5.1). They were emplaced above the Mesozoic sediments of the Indo-Pakistan Plate. The erosional debris was deposited on the ophiolitic slab as the Kanar Melange (DEJONG & SUBHANI 1979). Further to the east, the Gidar Dhor Formation and the Jamburo Formation (Hunting Survey Corp. 1960) of Paleocene and Paleocene-Eocene ages were deposited. Mostly marly and shaly with scattered limestone layers, they also contain layers with exotic blocks and volcanic agglomerates. The obduction of the ophiolitic sequences also led to the folding of the Mesozoic sediments of the Khuzdar Block.

It should be mentioned that besides the general rotation of the Indo-Pakistan Plate the Khuzdar Block also rotated against the Sulaiman Block. During the rotation in

Post-Oligocene time, a number of thrusts developed whereby large thrust sheets moved over the already folded Mesozoic sediments of the Khuzdar Block. In the northwest of the Khuzdar Block is the Kalat Thrust Sheet of the Kalat Plateau, which derived from the west. In the east there are the Kirthar Thrust Sheets which derived from the east (Figs. 5.10-A, 5.10-B, fold-out; 5.10-C).

The folds of Mesozoic–Early Tertiary sediments are dissected by a number of southwest- and southsoutheast- trending sinistral strike-slip faults. One of them, the Diwani Fault northwest of Khuzdar, caused considerable drag on the folds of the Mesozoic sediments, resulting in the conspicuous "Khuzdar Knot" or Khuzdar Syntaxis (Hunting Survey Corp. 1960). SAWAR & DEJONG (1984) explained the triangular shape of the Porali Plain south of Bela with the eastward rotation of the southern Khuzdar Block. In front of the eastern flank, the same process led to the most recent detachment of the sediments which were thrust eastward in the fold lobes of the Karachi Arc. The Karachi Arc is an east-verging belt of anticlinal folds, very similar to the south-verging Marri-Bugti nappes. Mainly rocks of Eocene and younger ages are involved.

5.232 Sulaiman Block

The Sulaiman Block is the basement block east of the Khuzdar Block. It is separated from the latter by the Kirthar Basement Fault which is assumed to be a sinistral strike-slip fault below the Kirthar Thrust Sheets.

The Sulaiman Block underwent a tectonic history different from that of the neighbouring Khuzdar Block. After the initial collision of the Indo-Pakistan Plate with the Afghan Block, the Khuzdar Block was slowed, whereas the Sulaiman Block continued to move northward. It formed the new leading edge of the Indo-Pakistan Plate. During the Oligocene it collided with and began underthrusting the Afghan Block. The Sulaiman Block was bent towards the north along the Sulaiman Basement Fault in the east and the overlying sediments were detached. They were moved southwards as nappes in large lobes now forming the Marri-Bugti Hills and the Sulaiman Range. BANKS & WARBURTON (1986) were the first to apply the modern concept of detachment tectonics to the nappes and identified passive-roof duplexes from cross-sections of Hunting Survey Corp. (1960). The southward movement of the Marri-Bugti nappes was restrained in the east by the Sulaiman Basement Fault that formed a buried obstacle in the deeper underground. It is assumed that the Sulaiman Basement Fault is a north-south trending step fault with a throw towards the west.

The nappes started to develop south of the Zhob Valley Thrust in the Oligocene and continued during the Miocene and Pliocene. They are from north to south (Fig. 5.16):

- the Muslimbagh-Zarra Nappe
- the Loralai Nappe
- the Mazar Drik Nappe and
- the Tadri-Pirkoh Nappe.

In the area northeast of Quetta, Hunting Survey Corp. (1960) identified the Gogai Nappe, and KAZMI (1979) described the Bibai Nappe below it which consists largely of volcanic agglomerates. Both nappes belong to a complex of thin-skinned thrusts in

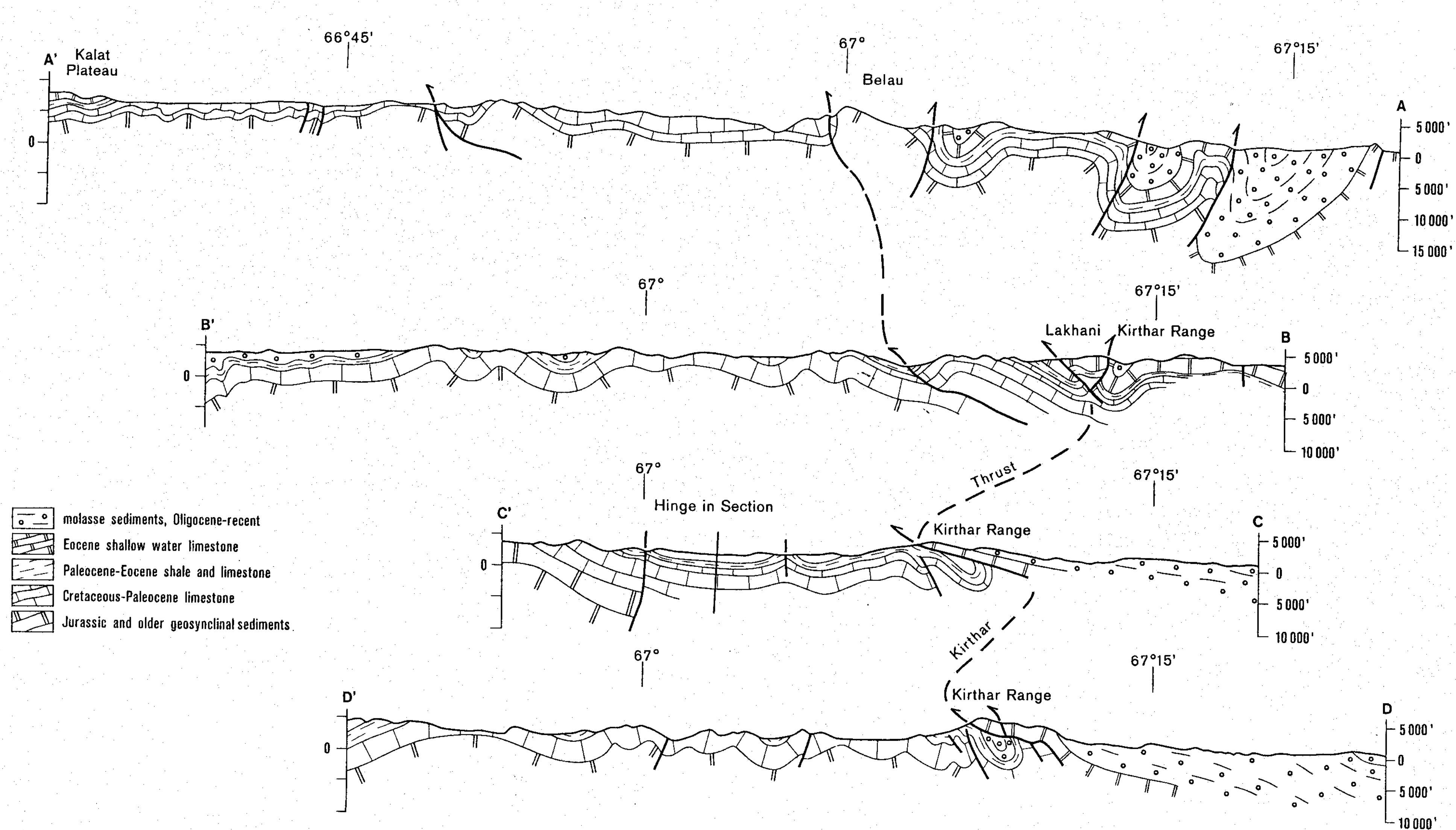


Fig. 5.10-C. Geologic cross sections through the Kirthar thrust sheets including interpretation of the thrust sheets as passive-roof out-of-the-syncline thrust complex. Location of cross-sections on Fig. 5.10-B (modified after Hunting Survey Corp. 1960, maps 15 & 16; BANNERT et al. 1992, fig. 20).

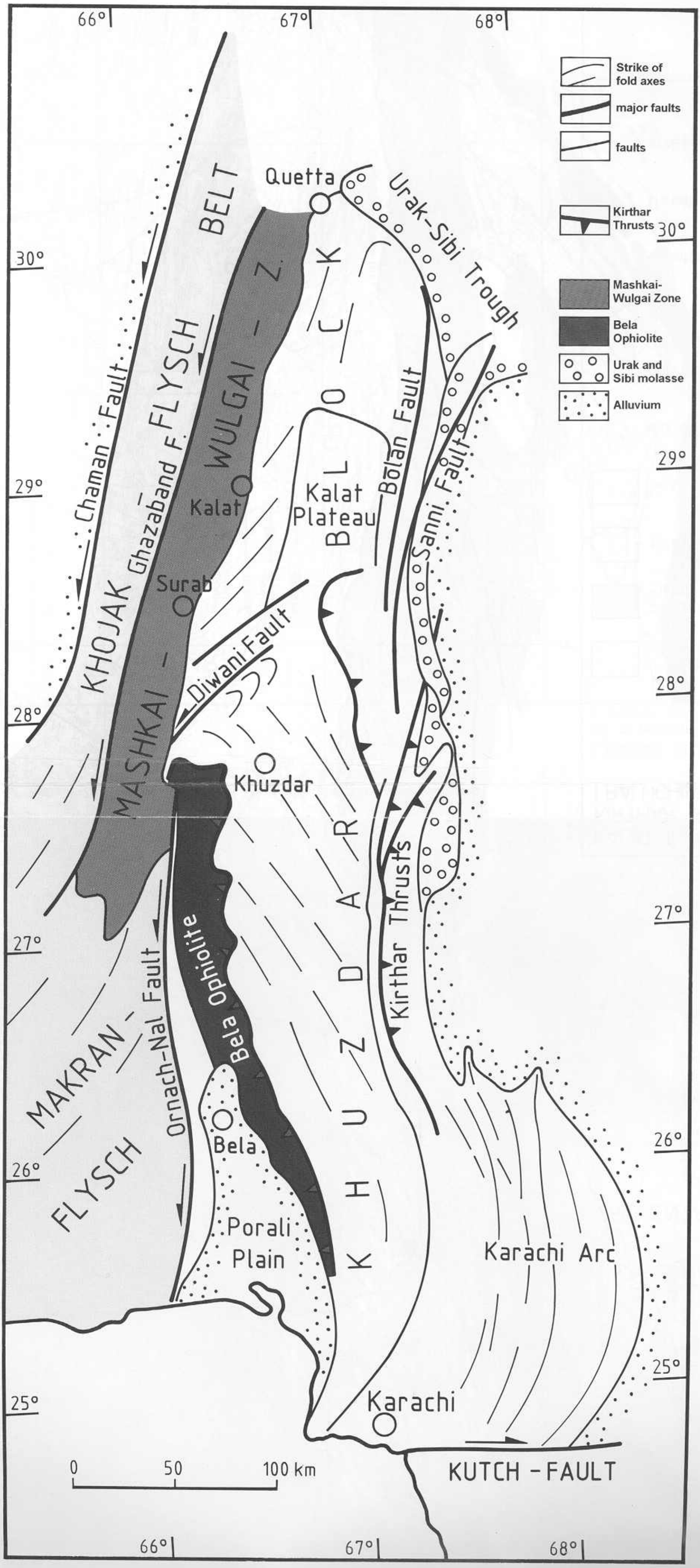


Fig. 5.9. Tectonic sketch map of the Khuzdar Block (after BANNERT et al. 1992, fig. 10).

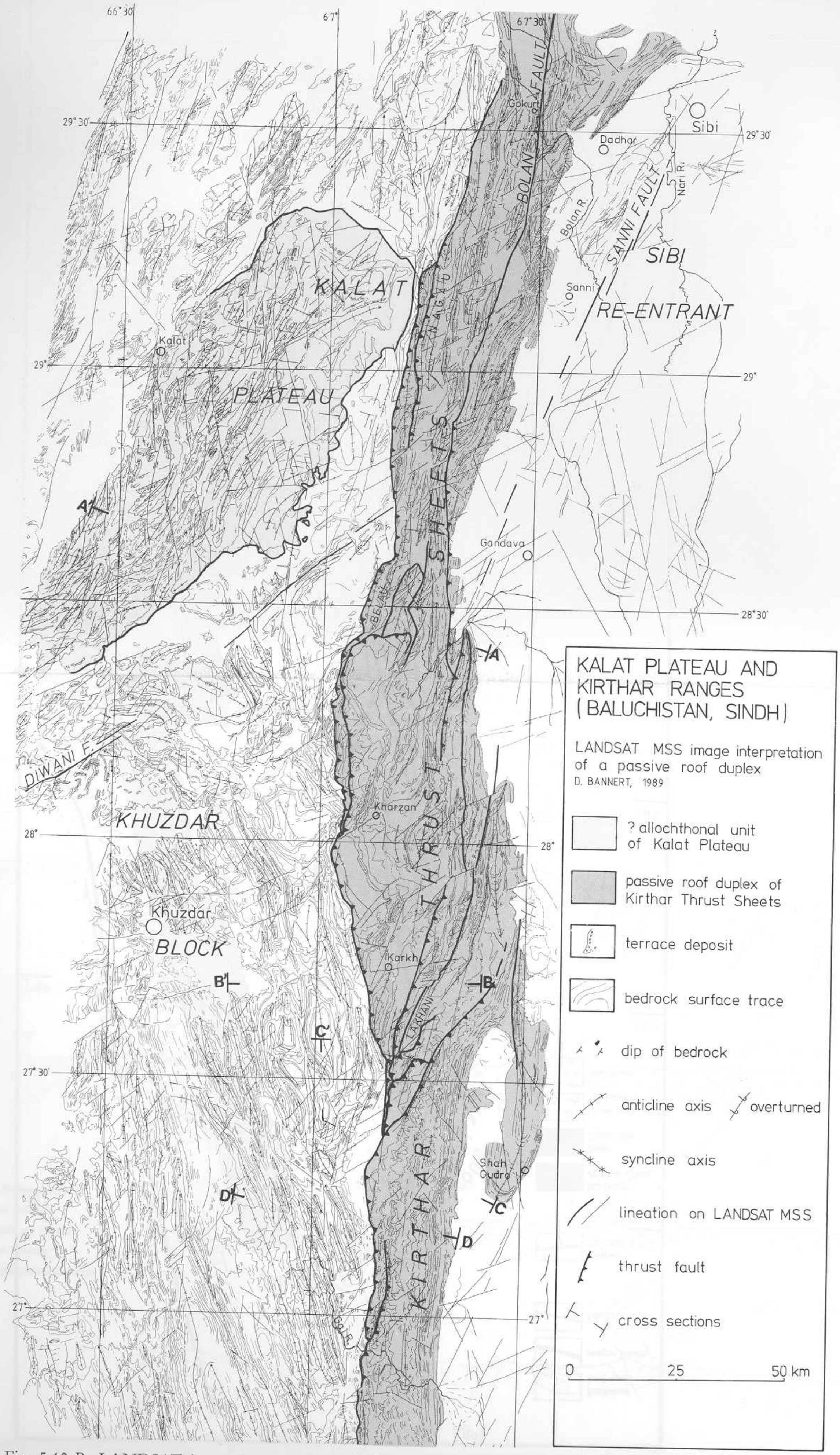


Fig. 5.10-B. LANDSAT image interpretation of Fig. 5.10-A showing the tectonic relationship between the Kirthar Thrust Sheets, the Kalat Plateau and the underlying folds of the Khuzdar Block (after BANNERT et al. 1992, fig. 19).

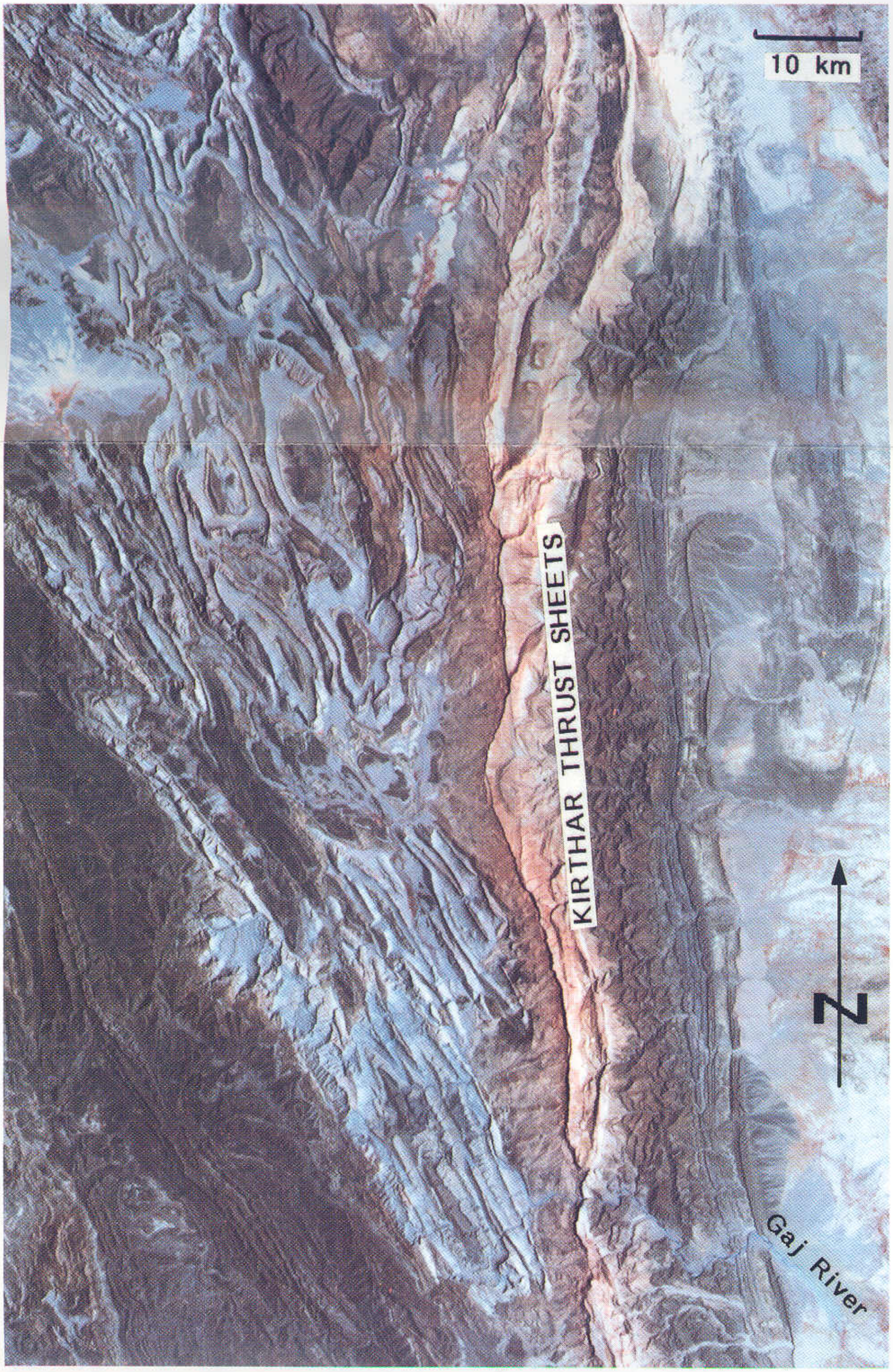


Fig. 5.10-A. LANDSAT image of the Kirthar Thrust Sheets, which are interpreted as out-of-the-syncline thrusts facing west, overriding the northwest trending folds of the Khuzdar Block. Refer to Fig. 5.10-B for tectonic details (after BANNERT et al. 1992, fig. 21).

the western part of the Muslimbagh-Zarra Nappe which occupy the western part of the Marri-Bugti area (Fig. 5.11). These nappes are from north to south: Guniar Ghar, Upper and Lower Ghundak, Takatu, Sur Nar, Gogai, Bibai, and Kach (BANNERT et al. 1989, BANNERT et al. 1992). The detachment horizon in this area belongs to the

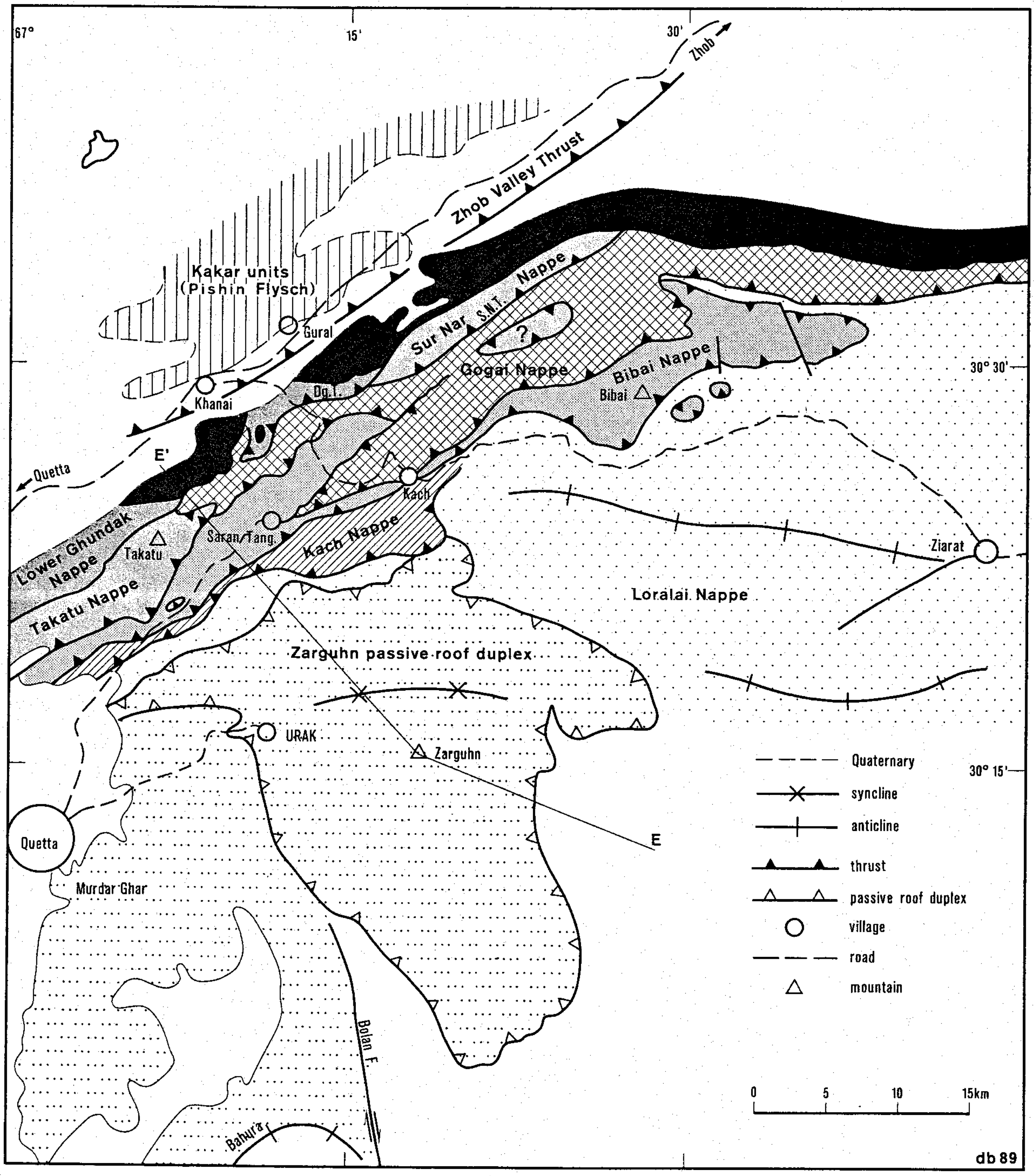


Fig. 5.11. Thin skinned detachment tectonics northeast of Quetta and Zarghun passive-roof duplex; cross-section E' – E: Fig. 5.14 (after BANNERT et al. 1992, fig. 29).

Paleocene – Early Eocene Ghazij Formation (see Chapter 3.41). These imbricate thrust sheets constitute what can be termed the Muslimbagh-Zarra Nappe. They are genetically related to the Bela-Waziristan Ophiolite Zone, the Muslimbagh Ophiolite Complex having been thrust southwards above them.

The root zone of the thin-skinned thrust sheets is covered by the Pleistocene valley fill of the western Zhob Valley. The Takatu and Ghundak sheets represent the most prominent of these thrust sheets forming isolated klippen high above the lower tectonic units (Fig. 5.12).

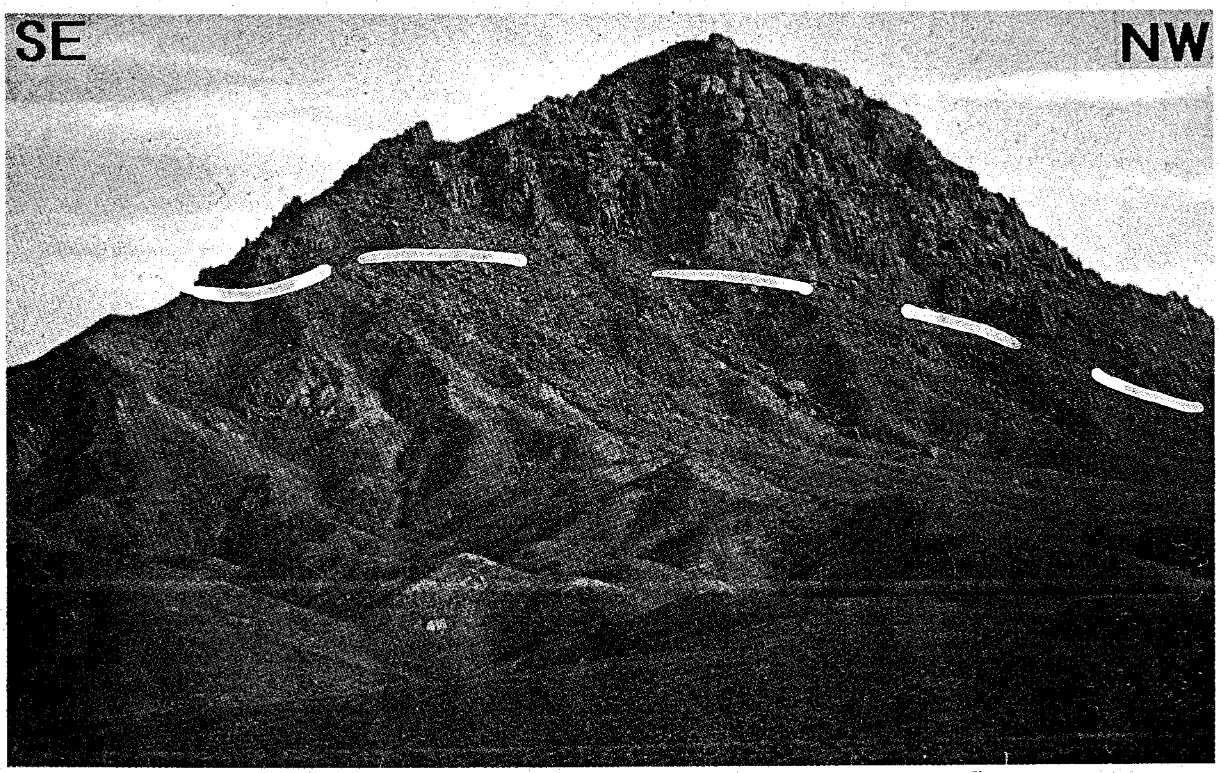


Fig. 5.12. Ghundak Mountain from the east, 7.6 km northwest of Kach along the road Khanai: The top of the mountain is Mesozoic Alozai Formation (Hunting Survey Corp. 1960) thrust from the north (right) above the Dungan Group (Hunting Survey Corp. 1960) and Ghazij Shale (Photo: D. BANNERT).

Further to the south, the thrust sheets dip more gently. Gogai and Bibai Nappes are morphologically very conspicuous. The Gogai Nappe extends farthest to the east and, together with the Bibai Nappe, may represent the southern boundary of the Bela-Waziristan Ophiolite Zone. The southernmost of these nappes is the Kach Nappe. It consists in part of conglomeratic molasse sediments of the Urak Group of Oligocene – Pleistocene age (Hunting Survey Corp. 1960; Fig. 5.13).

To the south of the Kach Nappe, Mt. Zarghun (3,562 m) is located representing the northern part of the Urak-Sibi Trough, that forms a syncline of Urak Group conglomerate lying on top of the Early–Middle Eocene shallow water Spintangi

Limestone and the Paleocene–Early Eocene Ghazij Shale. The Zarghun Syncline and Timur Syncline (to the southeast of Zarghun Syncline) form very conspicuous structures. The core of the Zarghun Syncline is the Zarghun Mountain, the highest mountain of the West Pakistan Foldbelt. The reason is the fast uplift of the two synclines towards the end of the Miocene when the Khuzdar Block from the south met with the advancing Marri-Bugti Nappes from the north. The northern part of the Urak-Sibi Trough was underthrusted by the horses of the Loralai Nappe. It became detached and was elevated as a passive-roof duplex within the Ghazij Formation. This is indicated by the upheavel of the Zarghun Syncline, the disharmonic, deformed anticline the Ghazij Formation and the Spintangi Limestone separating the Zarghun from the Timur Syncline, and the different fold pattern of the Urak-Sibi Trough (Figs. 5.14, 5.15).

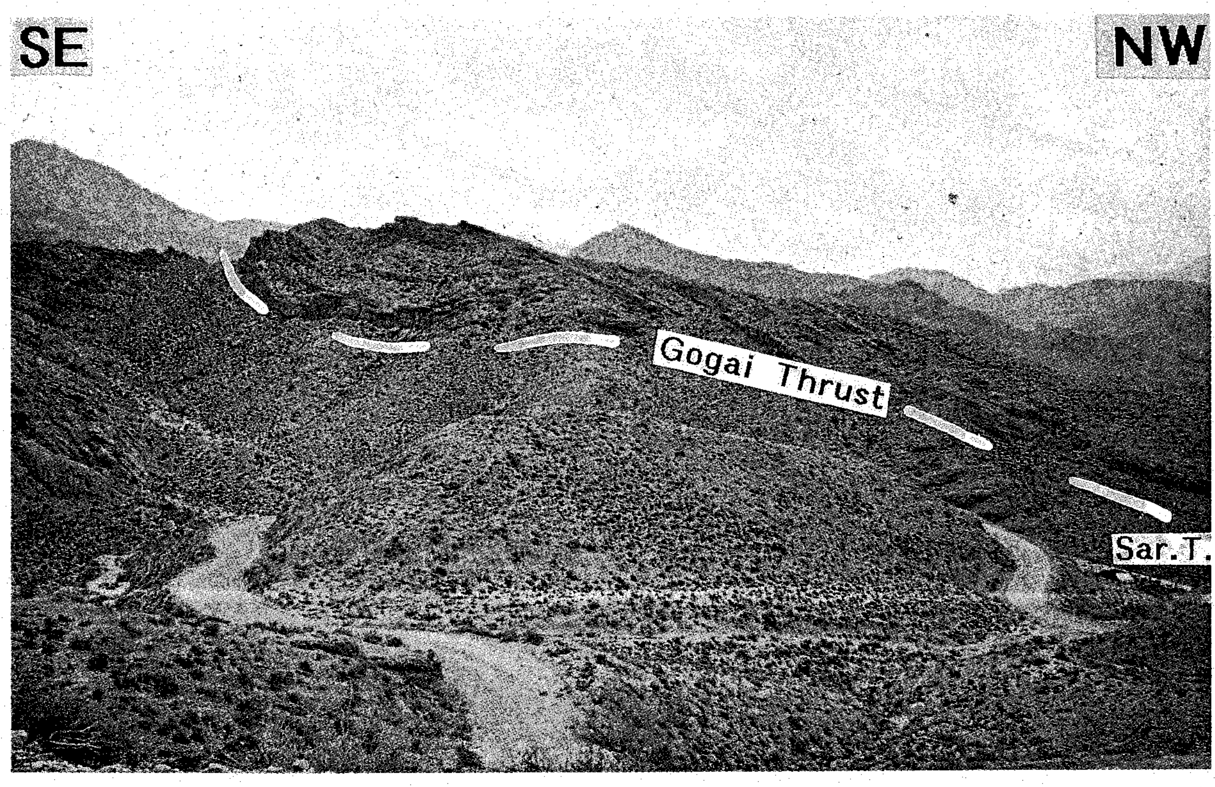


Fig. 5.13. View to the southwest towards Saran Tangi, 22 km northeast of Quetta, showing the Gogai Thrust within the Urak Group conglomerate. Note the differences in dip of the Urak Group conglomerate in the underlying Bibai Nappe (left) and in the Gogai Nappe (center) (Photo: D. BANNERT).

To the northeast, the straight Harnai Valley carries the Harnai Fault running within the Ghazij Formation. It is assumed that the Harnai Fault is a dextral side-slip fault that yields into the Karahi Thrust, the frontal thrust of the Loralai Nappe (Fig. 5.17). Next to the south is the Mazar-Drik Nappe. Its southern thrust is the Karmari Thrust.

Within the Mazar-Drik Nappe, south of the town of Kohlu, a group of Neogene volcanoes has been discovered on LANDSAT imagery (BANNERT et al. 1989). They

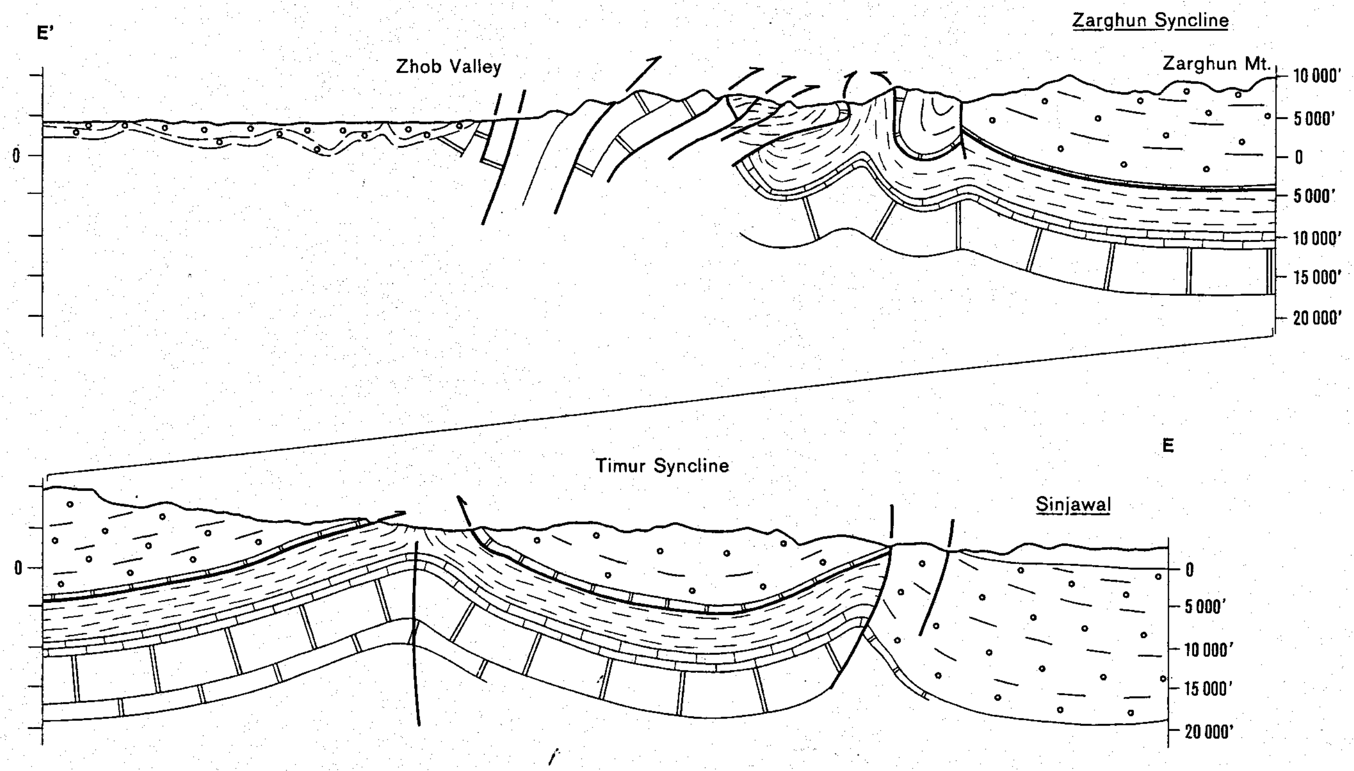


Fig. 5.14. Cross section through the Zarghun Syncline passive-roof duplex. Legend: See Fig. 5.10 C (after Hunting Survey Corp. 1960, map 26, section L-M-N; BANNERT et al. 1992, fig. 34).

are the first volcanoes found in Pakistan east of the Chaman Fault (Fig. 5.17). The youngest and southernmost nappe is the Tadri-Pirkoh Nappe with the Pirkoh Thrust as its frontal thrust (Fig. 5.16). In front of this thrust are the Sui and Uch anticlines, which are assumed to be the frontal folds leading into the syncline of the Indus Basin. It is not clear whether these two anticlines may also have been involved in thrusting towards the south. The frontal thrusts of all the large nappe units run within the Ghazij Shale, although much older detachment horizons have to be assumed. The Tadri-Pirkoh and Mazar-Drik Nappes also incorporate sediments of the Urak and Sibi Groups in their western parts.

The eastern extension of the Marri-Bugti Nappes is within the Sulaiman Range. The Sulaiman Range consists of a number of anticlines, the Sulaiman Anticlinorium, striking NNE with the separating synclines generally passing into vertical faults. The frontal thrusts of the nappes are represented by a number of faults belonging to the Domanda Fault System (after the Domanda Fault of HEMPHILL et al. 1973). The Karmari Thrust of the Mazar-Drik Nappe continues in the Western Domanda Fault (Fig. 5.17), and the Pirkoh Thrust extends into the Eastern Sulaiman Fault of the Sulaiman Ranges.

The southward advancing nappes were met with increasing friction along the Sulaiman Basement Fault. This caused the synclines to be squeezed out between the anticlines in the Sulaiman Anticlinorium and resulted in uplift of the Sulaiman Range. Meanwhile, the continued southward advance of the nappes in the Marri-Bugti area was facilitated by the development of the Western Sulaiman Transform Fault which in part was identified as the Kingri Fault by ROWLANDS (1978). A sinistral offset of

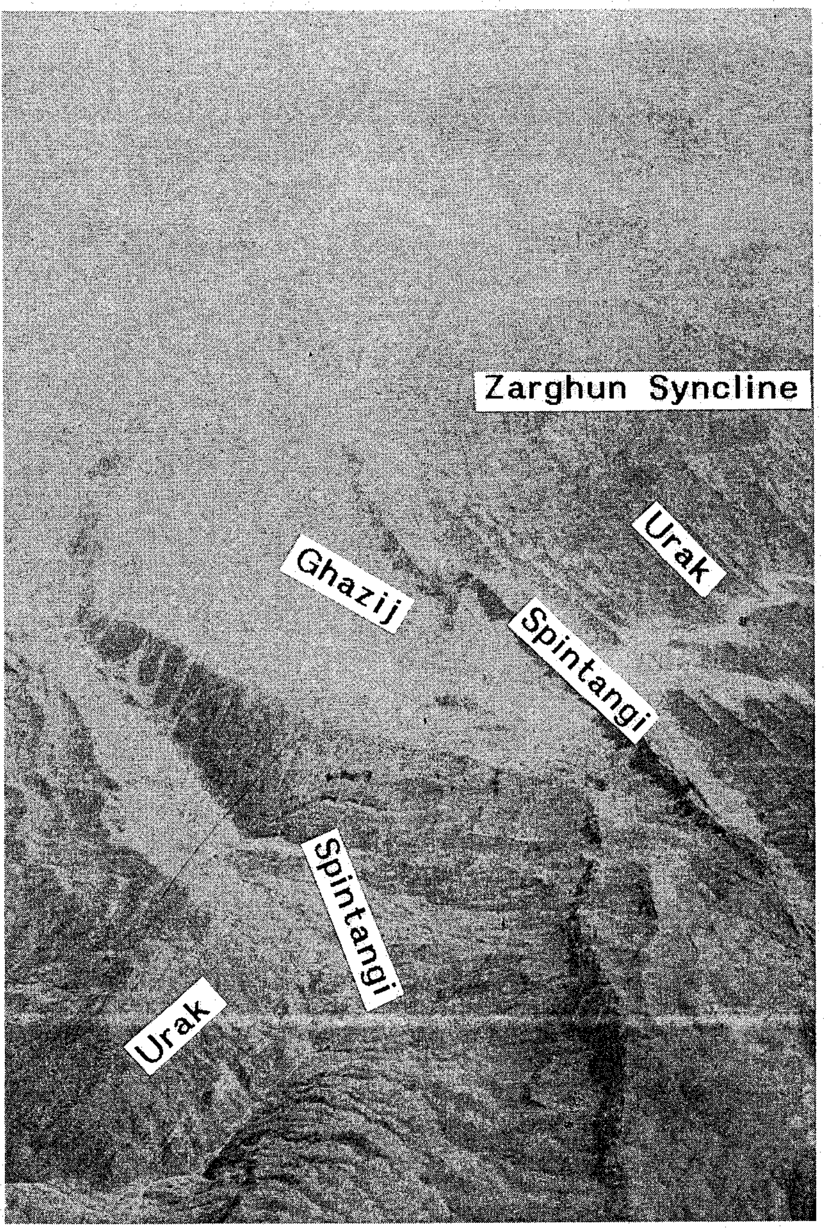


Fig. 5.15. View to the south of the anticline east of Quetta between the Zarghun Syncline (right) and the Timur Syncline (left): The core of this conspicuous anticline is the incompetent Eocene Ghazij Formation, which is the detachment horizon of the passive-roof thrust. Also note the banding within the Spintangi Limestone. Dark well bedded rocks on both sides of the picture belong to the Urak Group (Photo: D. BANNERT).

27 km - 30 km can be observed along the Western Sulaiman Transform Fault but the total amount of crustal shortening across this area is much greater as a result of internal structures within the nappes west of the fault and the presence of other sinistral faults such as the Barkhan Fault (Fig. 5.17).

The Sulaiman Basement Fault extends far to the north and possibly links-up with the Sarobi Fault east of Kabul. Its projection into the overlying sediments can be

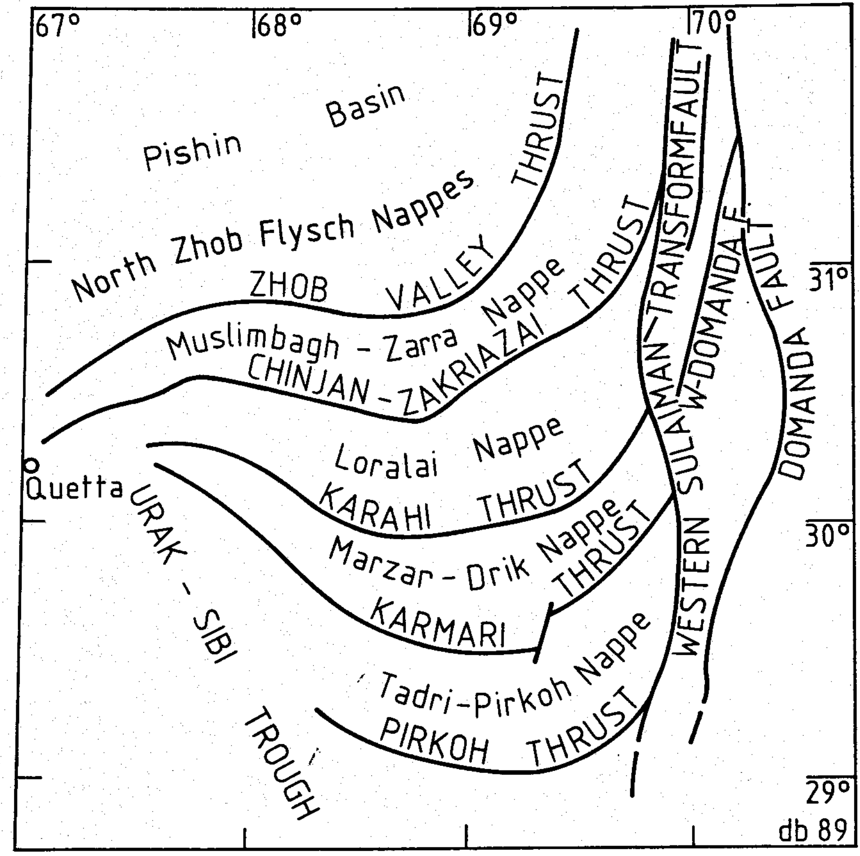


Fig. 5.16. Tectonic units of the Marri-Bugti Hills and the Sulaiman Anticlinorium (after BANNERT et al. 1989).

observed on LANDSAT imagery as a number of linear features, mostly faults. The folds of the Marri-Bugti Nappes yield northwards into a northern strike, until they are intersected by the northern extension of the Zhob Valley Thrust in the vicinity of the Waziristan Ophiolite Complex. East of the Sulaiman Basement Fault, the Indo-Pakistan Plate continued to move northward into the Himalaya Subduction Zone.

5.233 The Bela-Waziristan Ophiolite Zone

The rocks of the Bela-Waziristan Ophiolite Zone (Fig. 2.10) represent remnants of volcanics and sediments of the Tethys. The Tethys III Ocean (Fig. 6.4) was formerly about 4,000 km wide and located north of the Gondwana Continent, prior to its final break-up at the beginning of the Cretaceous. The Bela-Waziristan Ophiolite Zone is an elongated zone between the Khuzdar Block in the east and the Makran-Khojak-Pishin Flysch Zone in the west. Hunting Survey Corp. (1960) described a "directionless" fold pattern for this zone within the rocks of the Cretaceous Parh Group. LANDSAT imagery, however, shows a wide open fold pattern of Parh Group sediments that is generally in the north trend of the structural pattern of this area. A similar style of deformation is also present in the western part of the Muslimbagh-Zarra Nappe, south

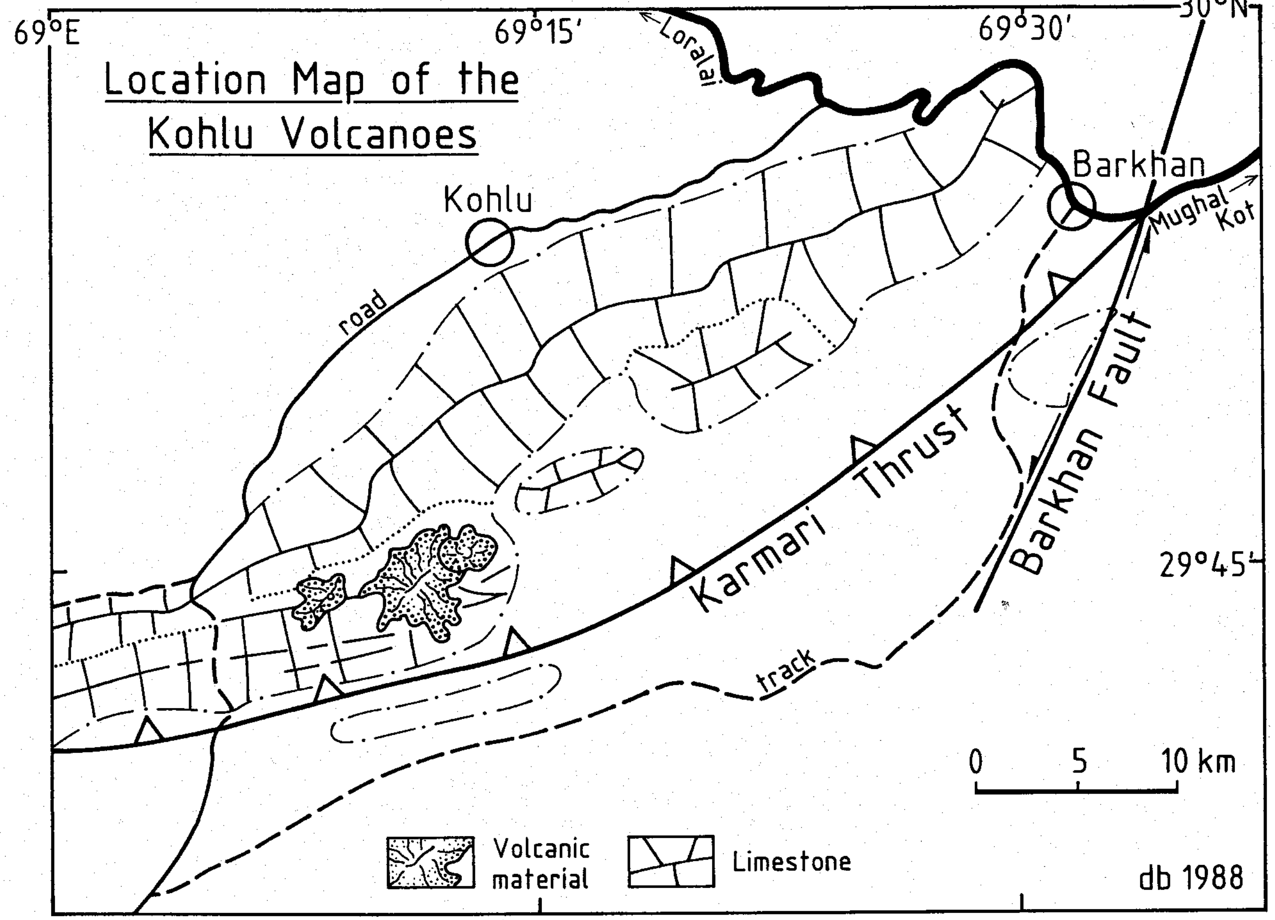


Fig. 5.17. Location map of the Kohlu volcanoes (after BANNERT et al. 1989).

of Zhob Valley, and in the northern part of the Loralai Nappe. South of Quetta the Bela-Waziristan Ophiolite Zone is characterized by a basin-and-range morphology. The ranges trend north, the alluvial lowlands between the ranges are presumably formed by faults.

Hunting Survey Corp. (1960) indicated pre-Parh Formation folding on their map 14 (Mashkai), sections A-B and C-D. A second deformation of the Bela-Waziristan Ophiolite Zone took place during the Paleocene with obduction of ophiolitic seafloor material in the Bela, Muslimbagh, Zhob and Waziristan areas. The obducted ophiolitic material was later thrust from the west to the east over the already folded Mesozoic sediments of the Khuzdar Block. The final stage was the thrusting of Oligo-Miocene flysch onto Cretaceous-Eocene calcareous sediments near Mashkai.

5.24 The Chagai-Ras Koh Volcanic Arc

North of the Makran Flysch Segment and west of the southern Khojak Flysch Segment lies the Chagai-Ras Koh Volcanic Arc (Fig. 2.7). FARHOUDI & KARIG (1977) recognized this area as being a volcanic arc associated with the subduction of the Arabian Plate under the southern margin of the Eurasian Plate which is here the Afghan Block. This model was later adapted by JACOB & QUITTMEYER (1979), LAWRENCE et al. (1981) and ARTHURTON et al. (1982), and is followed in this Chapter. SILLITOE (1978) assumed that the Chagai Geanticline and Ras Koh Geanticline represent a formerly continuous arc that was dissected into two parts along a sinistral wrench fault in the area that became the Dalbandin Trough. Magmatic activity in the arc extended from the Pre-Maestrichtian through the Miocene (Shor Koh intrusions, Hunting Survey Corp. 1960). The Koh-i-Sultan volcanism originated in the Pleistocene (ARTHURTON et al. 1982, Hunting Survey Corp. 1960).

The Chagai-Ras Koh Volcanic Arc began to emerge during the Late Cretaceous. It continued through the Paleocene/Eocene period. Towards the end of the Paleocene, the flysch was subjected to strong folding and thrusting, connected with the obduction of ophiolitic seafloor in the Ras Koh Geanticline. This took place at the time of the initial collision of the Indo-Pakistan Plate with the Afghan Block and the coeval obduction of oceanic seafloor in the Bela-Waziristan Ophiolite Zone.

There are a number of prominent faults, convex to the south, situated more or less along the strike of the sediments. Some of these faults have assumed the nature of thrusts to the south. From north to south these faults are:

- Great Chappar Fault (since the Late Pliocene)
- Laki Koh Fault (since the Mio-Pliocene at least)
- Kharan Fault (since Late Pliocene).

In the Late Paleocene, the Ras Koh flysch was obducted and thrust towards the north above a thrust convex to the north. In the Mirjawa Ranges, the Tozgi Koh Fault came into existence during the Pliocene faulting and folding. To the east, the Chaman Fault and associated sinistral transcurrent faults were formed, enabling the southward propagation of the accretionary flysch wedge of the Makran Flysch Segments and the deep indention of the Indo-Pakistan Plate into the southern rim of the Eurasian Plate. This collision left its direct marks in the Chagai-Ras Koh Volcanic Arc: In the southern Ras Koh Ranges, the flysch sediments were thrust northward on the Ras Koh Geanticline during the first phase of folding at the end of the Paleocene. During the collision, the fore-arc basin (the Dalbandin-Alam Reg Trough) remained more or less stable in its position. Only during or after the Pliocene, the Mashkhel Basin assumed the position of the fore-arc basin above the modern subduction zone.

5.25 The Makran-Khojak-Pishin Flysch Zone

The Makran-Khojak-Pishin Flysch Zone (Fig. 2.5) was formerly a single flysch trough that began to develop in the Late Cretaceous in front of the Afghan Block and the Kabul Block (ARTHURTON et al. 1982). Off the Makran coast, flysch sedimentation continued up to the present. The style of deformation in the three segments of the Makran-Khojak-Pishin Flysch Zone differs considerably from segment to segment.

In the Makran Segment, the sediments are a sequence of shale, turbidites and sandstones which were transported from the north into the trench over the subduction zone where the Arabian Plate is subducted under the Afghan Block.

During the Late Cretaceous and Paleocene, the Chagai and Ras Koh geanticlines formed a volcanic arc with an adjacent fore-arc basin to the south. The fore-arc basin (Dalbandin Trough) merged into the flysch geosyncline (= The Makran-Khojak-Pishin Flysch Zone). The shoreline progressed southwards corresponding to the emergence of the northern part which was affected by accretionary tectonics. The position of the volcanic arc still remained the same, although the alignment of Neogene volcanoes does not exactly follow the former trend (ARTHURTON et al. 1982; Fig. 6.12). DYKSTRA & BERNIE (1979) attributed this phenomenon to the segmentation of the underlying Makran Subduction Zone, which apparently has a shallower dip of less than 10° to the north in its western- and easternmost segments, compared to a dip of between 14° and 20° to the north in the two central segments. The fore-arc basin shifted southward and today forms the Helmand Basin (JACOB & QUITTMEYER 1979).

In the Makran segment, the sediments are piled on each other in thrust lobes (LEGGETT & PLATT 1984, figs. 3, 5, and 6). This style of deformation continues southward into the Arabian Sea (WHITE 1979). The major thrust planes dip northwards and have an arcuate shape convex to the south. The thrusts extend to the west into Iranian territory. LEGGETT & PLATT (1984) described terrane-bounding faults which separate blocks of a specific internal deformation from one another. They are interpreted as east-trending strike-slip faults. To the east, the thrusts link with the prominent north-trending transcurrent Chaman- and Ghazaband Faults which facilitated the northward indention of the Indo-Pakistan Plate into the southern margin of the Eurasian Plate. LAWRENCE & YEATS (1979) proposed a southern propagation of the Chaman Fault along which a left-lateral displacement occurred. This fault connects with the Ghunzakai Fault of Early Tertiary age which might be the oldest southwest extension of the Chaman Fault south of Chaman. During the further accretion of flysch sediments and volcanic rocks, the Chaman Fault extended southward through these rocks and continued into the Dalbandin Fault (= Usman Fault of LAWRENCE & YEATS 1979) which appears to be a southward thrust. The accretion of terrigenous material in the subduction zone south of the Afghanistan Block and the Lut Block continued while the Indo-Pakistan Plate moved north. Along the Chaman Fault, this motion was made possible by the continuing propagation of the Chaman Fault southwards through the newly accreted sediments which were folded and thrust southwards. From time to time, new regional thrusts were added towards the south:

- The oldest fault that branched off to the southwest from the sinistral Chaman Fault is the Dalbandin Fault.
- The second thrust affecting the accretionary wedge of the Oligo-Miocene Flysch is the Siahan Fault branching from the Chaman Fault north of 28° N.
- After the accretion of a new pile of sediments the Chaman Fault progressed further to the south and the Panjgur Fault thrust the flysch sediments upon each other. Farther south, the Chaman Fault dissolved into numerous parallel faults, some of them revealing a sinistral offset as observed in LANDSAT images. Near 28° N, the Ghazaband Fault and the Chaman Fault are separated by only a few km of the

southernmost Khojak Flysch. The Ghazaband Fault is sinistral, too. It assumed the southward movement of the Makran Flysch accretionary wedge.

- The Hoshab Fault is the next thrust to the south that branches from the Ghazaband Fault.
- Further to the south the Nal Rud Fault assumed a similar function. LANDSAT image interpretation was not conclusive as to whether or not this thrust links with the Ghazaband Fault (BANNERT et al. 1989).
- The most recent transformation of a sinistral strike-slip fault into a south verging thrust is the Ornach-Nal Fault that is east of, and en-echelon with, the Ghazaband Fault.

The surface expression of the accretionary prism in the Makran consists of imbricate thrust wedges and steep asymmetrical tight folds. The folds are narrow, partly overturned and connected with high angle reverse faults, convex to the south. The fold pattern as well as the reverse thrust faults generally follow an east trend. To the south, near the coast, the number of the reverse faults decrease considerably.

Prominent sets of tear faults account for a subordinate but important part of the young deformation of the area. LEGGETT & PLATT (1984) observed on LANDSAT imagery that these wrench faults offset the south verging thrusts in several places. Generally, they follow a northwest- and northeast-trending pattern. The northwest-faults are dextral, the northeast faults are sinistral. Both sets of faults are the result of the north-south compression affecting the accretionary wedge. PLATT & LEGGETT (1986) suggested underplating and underthrusting at the prism front to account for the concordant sequence from abyssal plain to shelf and near-shore facies through a slope mantle cover.

The Miocene and younger sediments in the coastal area are not as much affected by tectonic deformation as the older rocks of the central and northern Makran.

The thrust tectonics continue for some distance into the Gulf of Oman. WHITE (1979), analyzing continuous seismic profiles (recorded by RRS Shakleton), found the frontal folds of the accretion wedge approximately 100 km off the Makran coast.

Knowledge of the Khojak Segment of the flysch trough is still limited. The age of the flysch deposits is Oligocene and Miocene. In the area east of Chaman, tight folding and serizitization have been reported by LAWRENCE et al. (1981). In the Khojak Segment, no thrust tectonics have been observed. East of the Chaman Fault, the flysch belt is 30 km wide with north striking sediments that connect with the Makran flysch in the south and with the Pishin flysch north of the Zhob Valley, between 28° 30'N and the town of Chaman. This belt is accompanied in the east by the Ghazaband Fault which came into existence after the left-lateral side-slip motion along the Chaman Fault decreased, whereas the indention of the Indo-Pakistan Plate continued. The Khojak Segment was stretched extremely in the north direction, when the Makran-Khojak-Pishin Flysch Zone was severed along the Chaman Fault in the west and the Ghazaband Fault in the east. The stretching into the present north direction from a former northeast direction accompanied a rotation in an anticlockwise manner, parallel to the rotation of the Bela-Waziristan Ophiolite Zone adjacent to the east (BANNERT et al. 1989). More than 400 km of north displacement has occurred in this zone along numerous strike-slip faults. To the northeast of Chaman, the trend of the flysch sediments changed to the northeast, approaching the fold-and thrust lobes of the Pishin Basin. Along the Chaman Fault, LAWRENCE & YEATS (1979) observed sheared ophiolitic rocks, allowing the conclusion that the fault developed along the former subduction zone in front of the Afghan Block and the Eurasian Plate.

In the Pishin Segment, the depositional environment of the Late Paleocene to Eocene sediments graded from continental and epi-continental near Khost and Gardez (Afghanistan) to deep pelagic flysch in the southwest. The flysch trough deepened and widened into the Pishin Basin (= Katawaz Basin, CASSAIGNEAU 1979, ARTHAUD et al. 1977). There, the flysch of Middle Eocene age grades upwards into a Miocene sequence of shallow water sandstone and shale. Volcanoclastic material can be found throughout the entire sequence similar to the northern Makran flysch segment. The total thickness exceeds 8,000 m. The sediments have been folded since the Middle Eocene and a large part of the folding took place during the time when clastic sedimentation prevailed while the sedimentary basin progressively shallowed (TAPPONIER et al. 1981). WITTEKINDT & WEIPPERT (1973) and TAPPONIER et al. (1981) dated the beginning of the orogenetic movements in the Middle Eocene. The deformation continued at least into the Miocene because the molasse sediments of the Dada Formation are included in the subsequent nappe and thrust tectonics (Hunting Survey Corp. 1960). During the folding and thrusting the sedimentation continued and the Pishin Basin became shallower.

6. Palaeogeographic and geodynamic evolution

(Friedrich K. Bender)

As described in the preceeding Chapters, the geologic record in Pakistan reveals overwhelming evidence of plate tectonism, which, throughout the Phanerozoic, decisively influenced the stratigraphic and structural evolution. This in turn very much depended on the global development of the plates and their palaeo-latitudinal positions during geological history. Following the view of Dolan et al. 1987, diagrammatic reconstructions of global plate positions are shown on Fig. 6.1 (Early Cambrian), Fig. 6.2 (Early Permian), Fig. 6.3 (Early Jurassic), Fig. 6.4 (Late Cretaceous), and Fig. 6.5 (Late Eocene). Their view is considered also in discussing the development of the Indus Basin. The

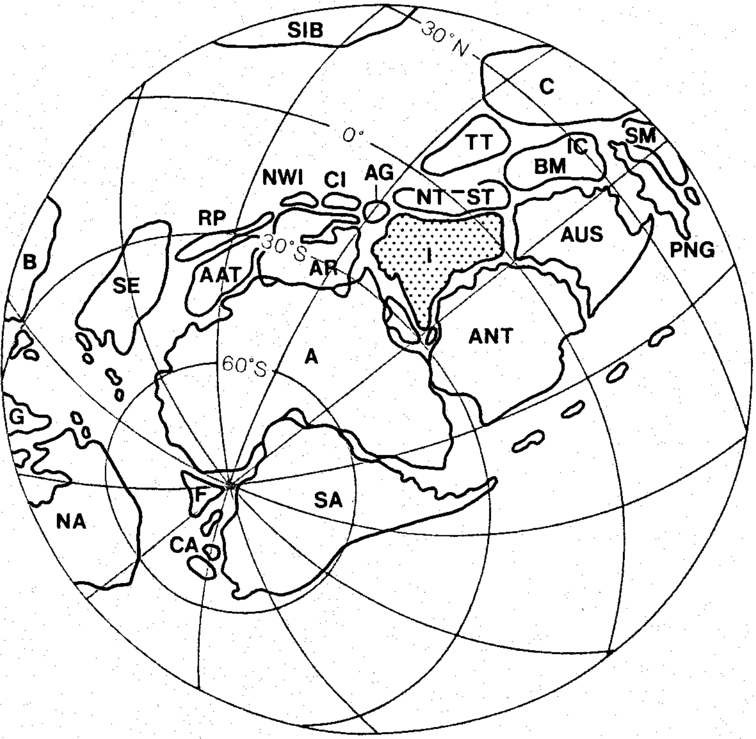


Fig. 6.1. Diagrammatic Plate reconstruction Early Cambrian, about 550 mio years ago (after Dolan et al. 1987, fig. 8; modified after Klootwijk 1979, Cocks & Fortey 1986).

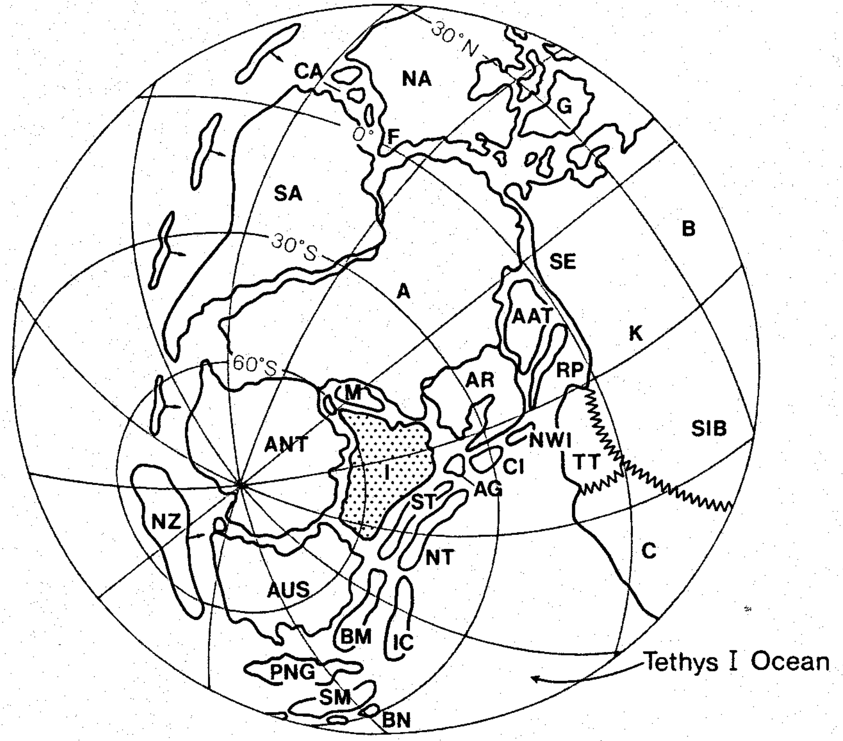


Fig. 6.2. Diagrammatic Plate reconstruction Early Permian, about 290 mio years ago (after Dolan et al. 1987, fig. 13; modified after Green et al. 1986).

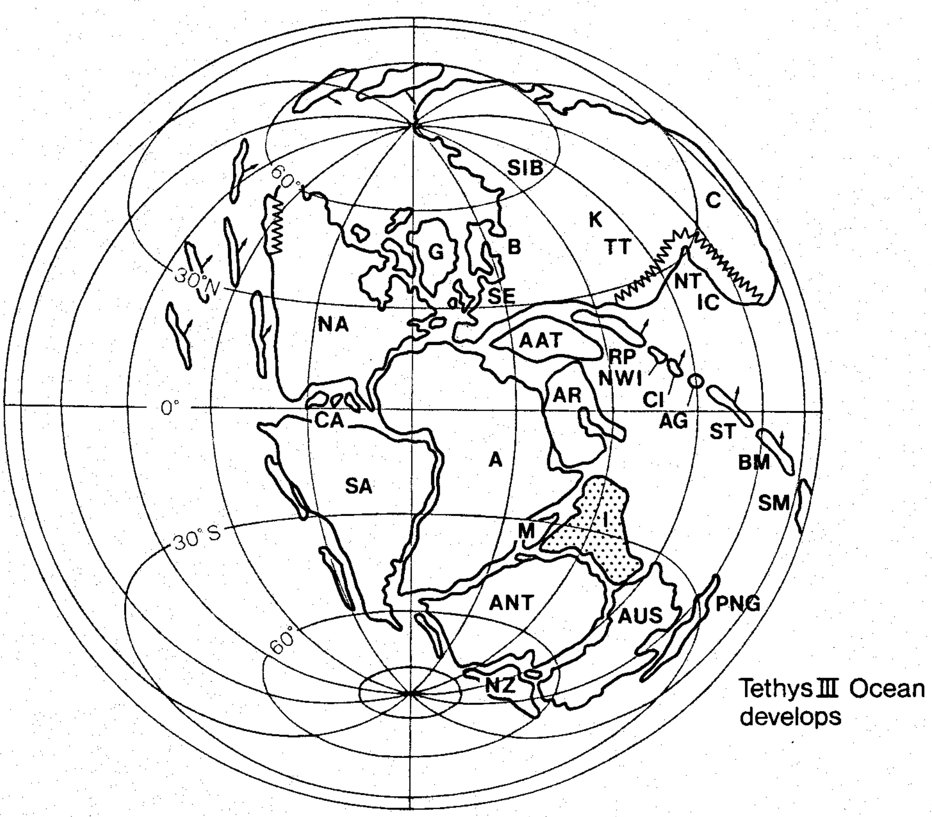
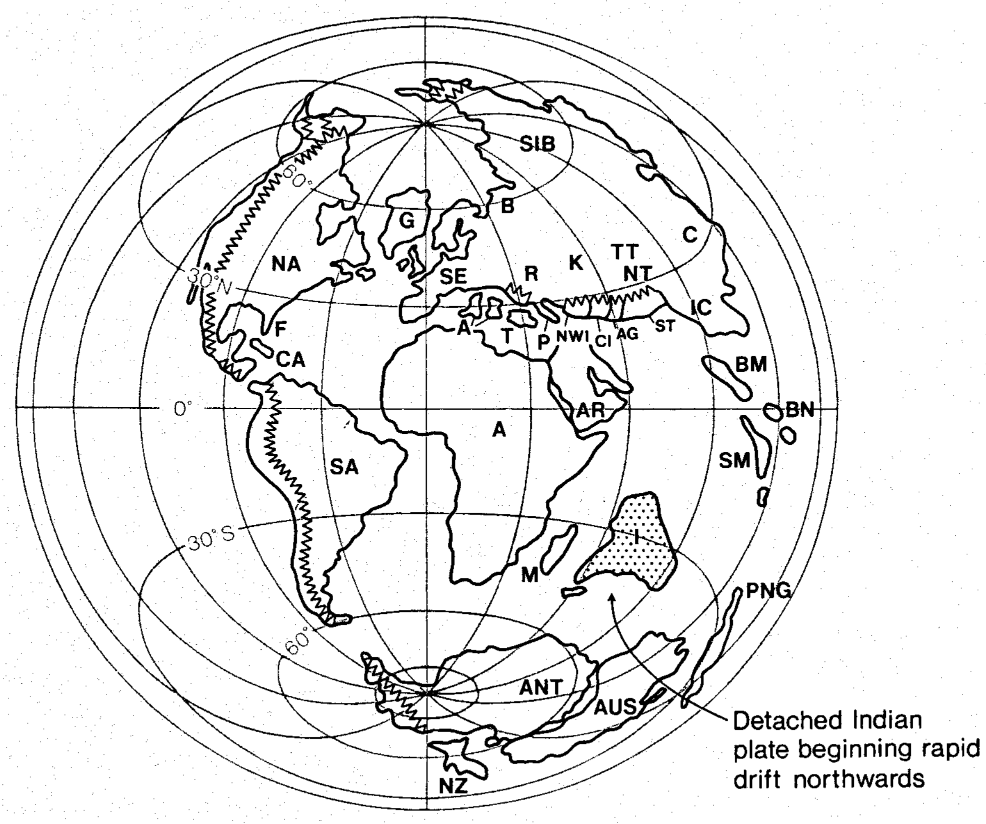


Fig. 6.3. Diagrammatic Plate reconstruction Early Jurassic, about 200 mio years ago (after Dolan et al. 1987, fig. 15; modified after Takin 1972, Powell 1979, Sengör 1984).

other literature on which the interpretation of the palaeogeographic evolution is mainly based is quoted extensively in Chapters 2 through 5, and therefore not fully repeated here.

Observations are too scarce to permit a reasonable reconstruction of the pre-Late Proterozoic geological history.



Detached Indian plate beginning rapid drift northwards

Fig. 6.4. Diagrammatic Plate reconstruction Late Cretaceous, about 80 mio years ago (after DOLAN et al. 1987, fig. 16; modified after SENGÖR 1984).

6.1 Late Proterozoic ("Infra-Cambrian") and Phanerozoic

Peneplenation of igneous and metamorphic basement rocks and a regional epeirogenic subsidence preceeded the deposition of **Late Proterozoic** and Cambrian sediments in the Salt Range and Potwar-Kohat areas, and probably in the major parts of the Punjab Province. The absence of basal coarse clastics in this region and the presence of shale, marl, and evaporite sequences directly above the basement indicate a very low relief during early Phanerozoic deposition (Salt Range Formation).

Further subsidence of the extensive Indus Basin during Early and Middle **Cambrian** times resulted in deposition of thick continental "red beds" with two major intercalations of dolomites and evaporites, and of glauconitic sandstones (Jhelum Group). These

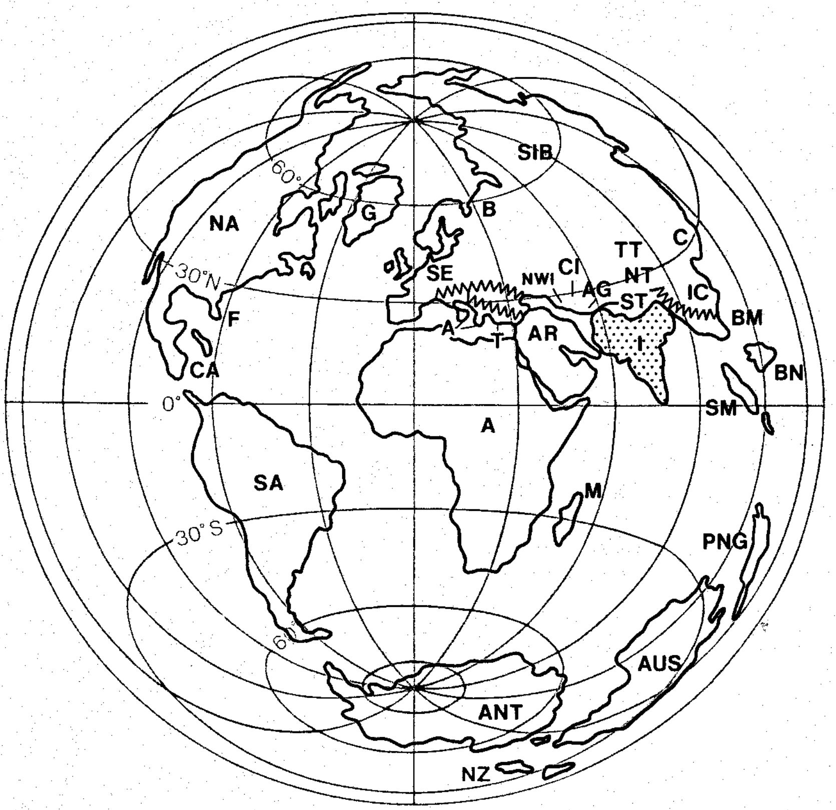


Fig. 6.5. Diagrammatic Plate reconstruction Late Eocene, about 40 mio years ago (after DOLAN et al. 1987, fig. 17) Legend for Figs. 6.1 to 6.5

Legend for Figs. 6.1 to 6.5

A	Africa
AAT	Apulia/Anatolide/Tauride (W. Greece/Italy/S. Turkey)
AG	Afghanistan (Seistan, Farah, Helmand, Kabul Blocks)
AR	Arabia
ANT	Antarctica
AUS	Australia
B	Baltic
BM	Burma/Malaya
BN	Borneo
C	China (North and South)
CA	Central America
CI	Central Iran
F	Florida
G	Greenland
I	India
IC	Indo-China
K	Kazakhstan
KA	Kolyma
M	Madagascar
NA	North America
NT	North Tibet
NWI	Northwest Iran
NZ	New Zealand
PNG	Papua-New Guinea (+ parts of Banda Arc)
RP	Rhodope/Pontide (E. Greece/N. Turkey)
SA	South America
SE	Southern Europe
SIB	Siberia
SM	Sumatra (+parts of Borneo, Java, Sulawesi, etc.)
ST	South Tibet
TT	Turan/Tarim
∧∧∧∧∧	Suturing

intercalations are indicative of marine ingressions. According to the very restricted outcrop belts and scarce subsurface information from a number of widely scattered oil exploratory wells, the basin may have had a south-north orientation with marine ingressions from the east. Lateral variations of the lithofacies of the sediments suggest more open and deeper marine depositional environment farther away from the margin of the Indo-Pakistan Craton (Fig. 6.6). Closer to the northern edge of the Craton, Early Cambrian faunas were identified in the Hazara Formation (see Chapter 3.2). Together with the underlying non-fossiliferous Abbottabad Group, TALENT & MAWSON (1979) considered the carbonates, pelites and arenites as lateral time-equivalents of the Late Proterozoic-Cambrian sequences of the Salt Range. These earliest sediments were deformed, metamorphosed and then intruded by granites (Mansehra granite, 514 mio years; LEFORT et al. 1980).

South of the Salt Range Thrust (SRT), no Late Cambrian to Permian (latest Carboniferous ?) sequences have been observed. The Cambrian is in parts truncated as result of erosion at the base of the **Permian**. The hiatus is generally explained by the existence of a stable and emerged Gondwana Continent in this region of Pakistan which would mean a period of about 250 mio years of non-deposition and erosion, or some deposition and subsequent erosion. Because Paleozoic sediments covering the time-span of the hiatus exist, however, in the region north of the SRT, as well as in Afghanistan, in Iran and in northwest India, remnants of these sediments might still be found in the Indus Basin south of it.

North of the SRT, Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian sequences are present (see Chapters 3.1 and 3.2). Middle to Late (?) **Ordovician** strata were observed in a carbonate/siltstone/quartzite sequence (TALENT et al. 1982). Rocks of undisputed **Silurian** age have so far not been found in Pakistan, though they could be expected beneath the Nowshera limestone (TALENT et al. 1982).

Early, Middle and Late **Devonian** sediments appear in Chitral District (TALENT et al. 1982, TALENT et al. 1988), and sediments of Early Devonian age in Peshawar District (TAHIRKHELI 1969), and in the Khyber Agency (KHAN, M. A. 1969).

Carboniferous bio-stratigraphy is not clearly documented in Pakistan except for some Early Carboniferous strata identified at Moshkai Mela in Khyber Agency, and Late Carboniferous rocks in northwest Gilgit Agency (TALENT & MAWSON 1979).

The bio-stratigraphy of **Permian** strata of the Salt Range is well documented, among others by KUMMEL & TEICHERT (1970). Permian rocks are also present north of the Main Boundary Thrust, as for example in the Khyber Agency, in Chitral and in the upper Hunza Valley (TALENT et al. 1982, GAETANI et al. 1990).

All these Paleozoic sequences in the northern part of Pakistan, except for some rocks of Permian age, indicate long periods of deposition in a marine environment, in contrast to the depositional hiatus elsewhere on the Gondwana Continent. These observations lead to the assumption of a seaway connection east-ward from Central Iran and Afghanistan in order to allow the Paleozoic sediments to be accumulated on the edge of Gondwana. The same could be explained by the existence of rifts, or small, elongated oceanic basins in this region. In any case, the presence of thick, mostly marine Cambrian to Permian sequences must have been related to initial phases of fragmentation of Gondwana, which actually started during Early Carboniferous to Early Triassic times. This explanation is further supported by widespread volcanic

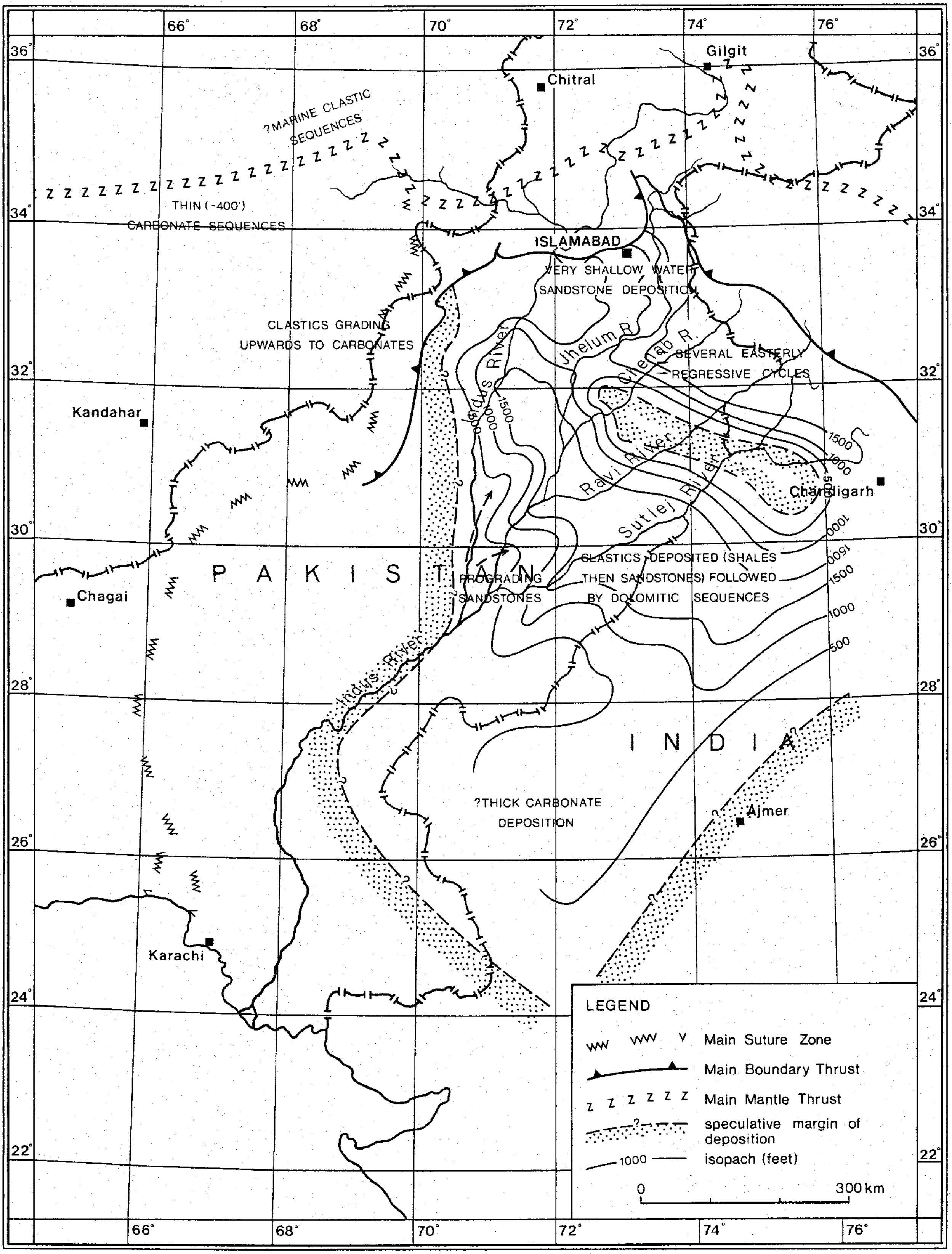

66°
68°
70°
72°
74°
76°
36°
34°
32°
30°
28°
26°
24°
22°
Gilgit
Chitral
?MARINE CLASTIC SEQUENCES
THIN (-400') CARBONATE SEQUENCES
ISLAMABAD
VERY SHALLOW WATER SANDSTONE DEPOSITION
CLASTICS GRADING UPWARDS TO CARBONATES
Jhelum R.
Chenab R.
Indus River
Ravi River
Sutlej River
Beas R.
SEVERAL EASTERLY REGRESSIVE CYCLES
Kandahar
Chandigarh
Chagai
P A K I S T A N
PROGRADING SANDSTONES
CLASTICS DEPOSITED (SHALES THEN SANDSTONES) FOLLOWED BY DOLOMITIC SEQUENCES
500
1000
1500
I N D I A
?THICK CARBONATE DEPOSITION
Ajmer
Karachi
LEGEND
Main Suture Zone
Main Boundary Thrust
Main Mantle Thrust
speculative margin of deposition
1000
isopach (feet)
0
300 km

Fig. 6.6. Cambrian depositional patterns (after DOLAN et al. 1987, fig. 37).

agglomerates ("Agglomeratic Slate") and intermediate volcanic flows and tuffs ("Panjal-Kashmir Trap"), in Kashmir, and around the northern part of the Hazara-Kashmir Syntaxis; they range in age from Late Carboniferous to Permian. The Panjal-Kashmir Trap has been taken as an evidence of an incipient Paleozoic sea between Gondwana and Kashmir-Hazara before the Indo-Pakistan Plate fragmented from Gondwana (BUTT et al. 1985).

Following the Late Cambrian to Carboniferous hiatus, Early Permian deposition started with tillite and other sediments related to peri-glacial environments (Tobra Formation), which derived from the northward retreating Permo-Carboniferous ice cap (Fig. 6.7). The overlying Dandot, Warchha, and Sardhai Formations of the Early Permian Nilawahan Group are of dominantly continental origin with fluviatile and lacustrine depositional environments. They include evidence of minor marine ingressions. The stratigraphic development implies epeirogenic subsidence in the region of the present Upper Indus Basin. A south-north oriented Basin was formed, similar to the Infra-Cambrian-Cambrian sag.

The sequences of the late Early Permian and the Late Permian Zaluch Group accumulated in an open marine, shallow shelf region, as evidenced by the dominantly calcareous-sandy lithology and abundant fossils (see Chapter 3.2). With the beginning of the Late Permian, there is a distinct change of the facies which indicates an upwarp to the east and a shift of the basin axis to the west compared with that of the Early Permian (Fig. 6.7), apparently as a result of regional rifting, tilting and subsidence to the west.

6.2 Mesozoic

Early **Triassic** sequences of calcareous rocks with sandstone and shale intercalations (Mianwali Formation) conformably overlie Late Permian strata, apparently after a short hiatus. Middle Triassic is represented by sandstone and shale, and massive, white sandstone (Tredian Formation), Upper Triassic by dolomite and dolomitic limestone with some marl and shale (Kingriali Formation).

As the facies distribution shows, the basin extended considerably to the south and occupied the present Lower Indus Basin, while its axis shifted further to the west as compared with the basin during the Permian. The clastic sediments originated mainly from the uplifted area on the Gondwana Continent in the east; depositional pattern points to marine ingressions from the north. Here, in the area of Mianwali, coal and interbedded limestones suggest periodic changes of marine and terrestrial depositional environment (Fig. 6.8). The continuing shift of the depocentre of sedimentation to the west may be explained by incipient rifting accompanied by further uprise of the region east of the depositional zero line.

Sedimentation during the **Jurassic** time in the Upper Indus Basin (Potwar/Kohat area) differed from that in the Lower Indus Basin and the West Pakistan Foldbelt (see Chapter 2.23). Whereas in the Upper Indus Basin mainly sandy-shaly sequences were laid down during the Early (Datta and Shinawari Formations) and Late Jurassic (lower part of Chichali Formation), calcareous deposition prevailed throughout the

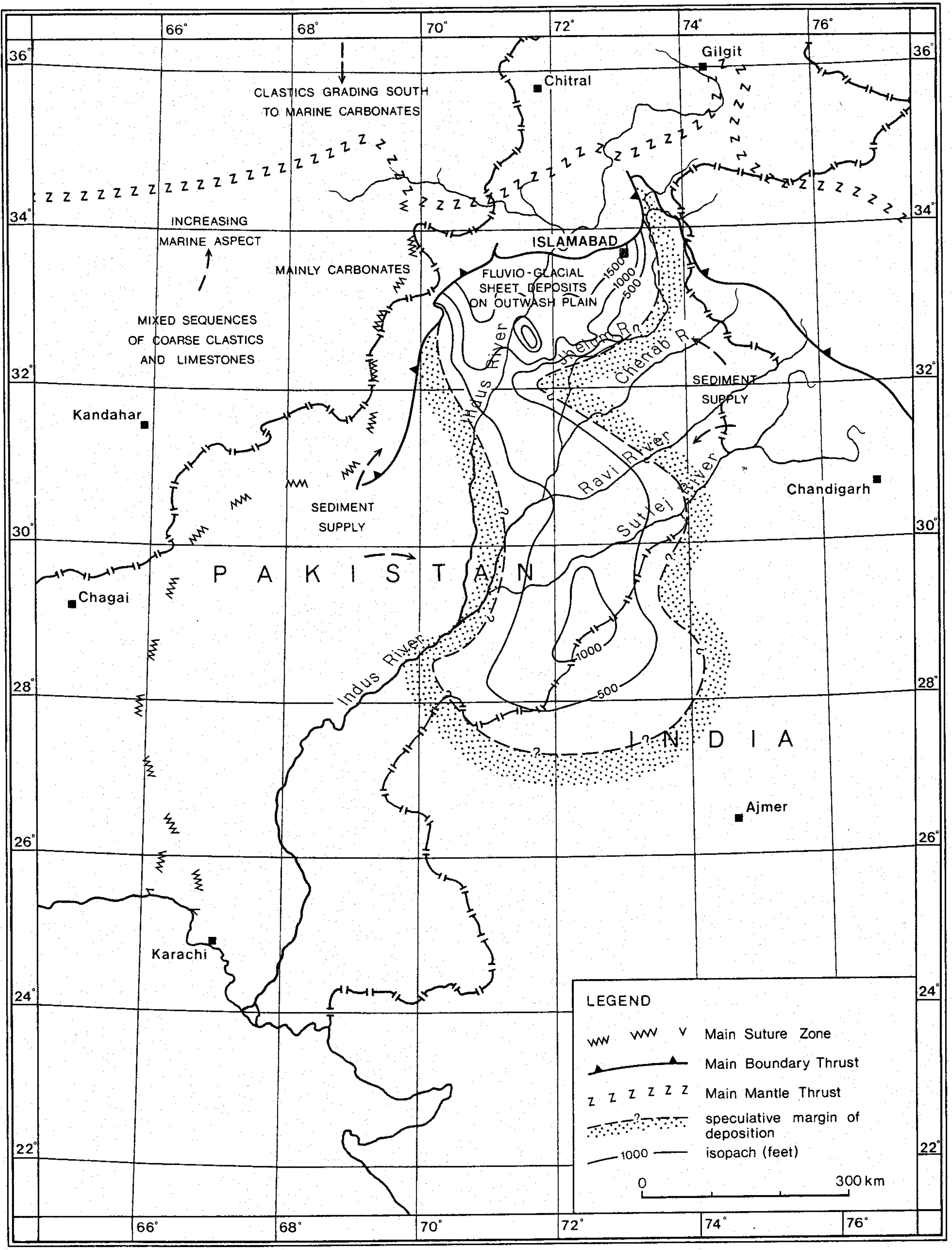


Fig. 6.7. Early Permian depositional patterns (after DOLAN et al. 1987, fig. 40).

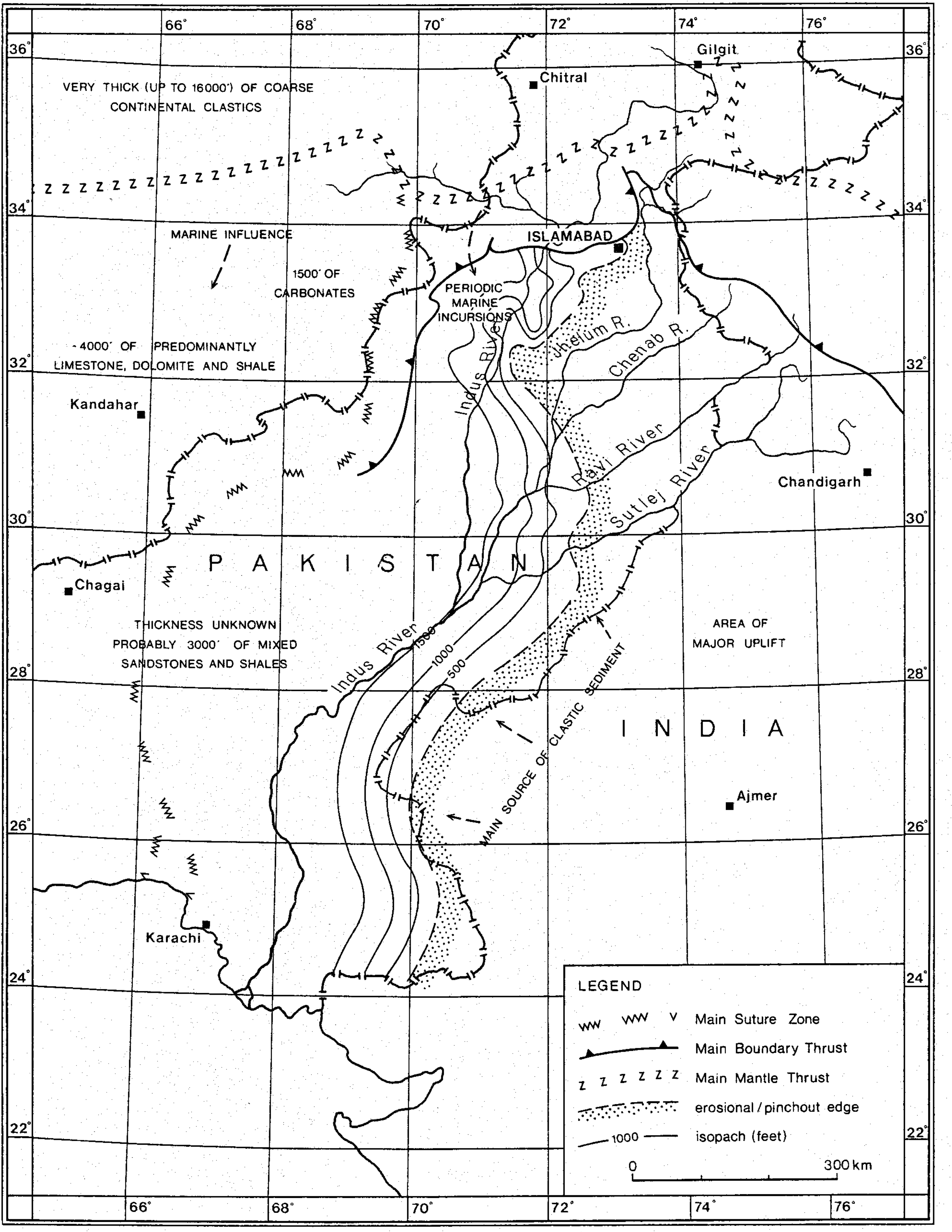


Fig. 6.8. Triassic depositional patterns (after DOLAN et al. 1987, fig. 42).

entire Jurassic in the Lower Indus Basin. During the Jurassic the Basin had a general north-south direction, similar to the Basin in the Triassic (Fig. 6.8), but probably extended further to the east.

The facies distribution points to shallow marine and deltaic environments (including coal) at the eastern margin of the basin, with clastic sediment transport coming from the east. Further west of this belt, the Jurassic sequence originated dominantly as limestones with some shales in a pelagic shelf depositional environment, in a subsiding intracratonic basin. In the West Pakistan Foldbelt, thick oolitic limestones developed in a shallow shelf region. About 30 km south of Quetta (Darwaza), a thin bed of boulders, cobbles and pebbles of oolitic limestone in a silty matrix at the base of this sequence points to high energy environment of deposition. It is conceivable that this feature was caused by the nearness of the shelf edge with deep water marine sedimentation farther to the west. The Jurassic edge of the shelf might have followed an initial suture or hinge line which is now marked by the Ornach-Nal, Ghazaband, Chaman-Gardez bundle of major faults (Fig. 5.10 A), that, in the south, separates the Lower Indus Basin from the Baluchistan tectonic units.

The palaeogeographic evolution of Baluchistan ("Belochistan" is here defined as the part of Pakistan west of about 67° longitude with the Zhob, Dalbandin, Mashkel and Makran areas) is different from that east of it, presumably from the Triassic to the Paleocene. During Early Jurassic to the Paleocene, the development of the rock sequences was influenced by the formation of the Tethys III Ocean (Fig. 6.3), as a result of the beginning and further migration of the Indo-Pakistan Plate away from the African and Australian Plates, and the splitting off and moving northwards of microcontinents. Structurally, the entire rock sequence west of about 77° longitude was and still is under the influence of the Arabian Plate northward migration, whereas the area to the east was dominated by the Indo-Pakistan Plate migration (Fig. 6.9). There was lateral segmentation in the framework and deposition within the Tethys seaway reflecting this fact, and probably subduction west of 77° longitude started in the Mesozoic.

With that, Jurassic sediments would have been deposited at a considerable distance from the Indo-Pakistan Continent; the Jurassic position of Baluchistan would be entirely speculative. For these reasons, and because of the paucity of information on the development of Jurassic sequences in Baluchistan, a detailed palaeogeographic reconstruction appears to be without proper base.

Throughout the **Cretaceous**, marine deposition continued in the Lower Indus Basin, progressing from mainly fine clastics with some carbonates (limestones, marls, shales), upward to limestones and marls with local sandstones and conglomerates. This sequence includes the Sembar, Goru, Parh, Mughal Kot, Fort Munro, and Pab/Moro Formations (see Chapter 3.33). In the Upper Indus Basin, the rock sequences developed a more sandy facies (Chichali, Lumshiwal formations) during late Early and Middle Cretaceous times also in a continental environment. During these periods, parts of the Basin apparently emerged and were covered by the sea again in Late Cretaceous (Kawagarh Formation).

The facies distribution during the Early Cretaceous reveals a steadily subsiding basin parallel to, and west of, the assumed basin edge, with a coal-bearing deltaic sandstone belt north of 30° latitude. Sediments more than 3,000 m thick accumulated in the southern part of the Lower Indus Basin, thinning toward the west. In the extreme western part of Pakistan, rapid thickening of the Lower Cretaceous sequence points to fast subsidence and accumulation of pelagic, deep water sediments, mainly shales. This conspicuous feature may reflect a shelf edge similar to the assumed edge in the Jurassic.

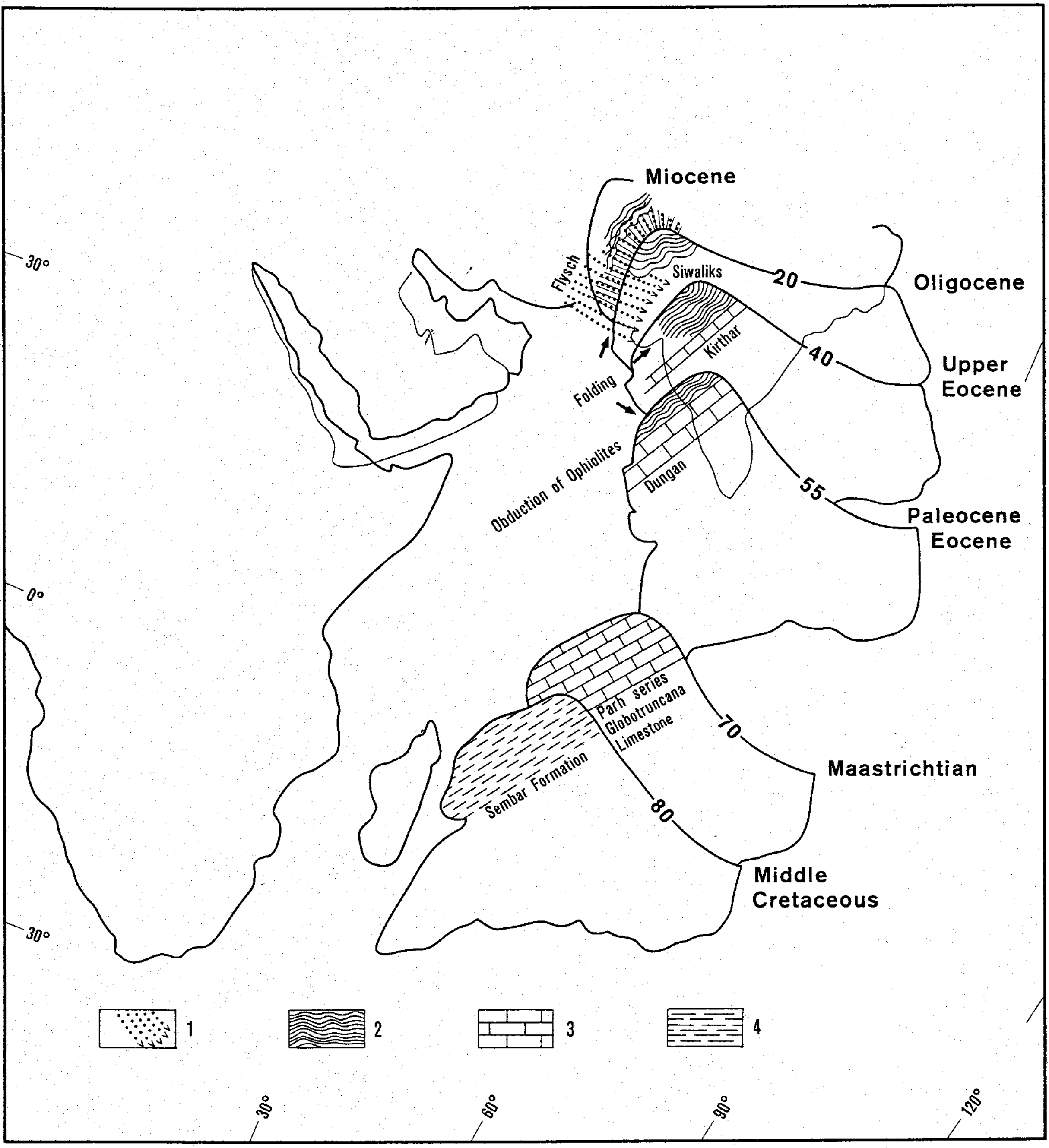


Fig. 6.9. Northward drift of Indo-Pakistan Plate during Middle Cretaceous through Miocene (modified after POWELL 1979).

The absence of Cretaceous strata in the Potwar area is explained by erosion rather than non-deposition; this applies also to the eastern edge of the Basin beyond the zero line, where, to a certain extent, Cretaceous sequences might have been formed but were eroded during Early Tertiary times.

Late Cretaceous sequences developed with marginal marine sandstones west of the erosional or pinchout edge of the Basin. The edge followed in general a SSW to NNE direction, comparable with the basin edge in the Early Cretaceous. In the Potwar area and in parts of the Kohat area, upper Cretaceous sediments are apparently absent, perhaps as a result of erosion during Early Tertiary.

The depositional pattern indicates the development of a progressively more complex structure within the Basin. In the area between Jacobabad and Sukkur, the northeast oriented "Jacobabad High" (Fig. 7.1) without sediment deposition (or little deposition and subsequent erosion), divided the Lower Indus Basin into two sub-basins, the Sulaiman Foredeep in the north, and the Kirthar/Karachi Trough in the south (see Chapter 7).

Coarse clastics were laid down at the northwestern side of the Sulaiman depocentre, indicating the existence of an exposed region somewhere to the northwest that is now subducted beneath the suture zone. This source of clastics might have been also responsible for the widespread deposition of the Pab Formation sandstones (see Chapter 3.33), although some authors believe these clastics were derived from the east (for example WHITE 1983).

Evidence of a volcanic facies in the West Pakistan Foldbelt in Late Jurassic/Early Cretaceous times (see Chapter 5.23) may have been related to the beginning of sea-floor spreading between India and Madagascar (Fig. 6.4). The rifting in this region led, during the Cretaceous, to synsedimentary faulting, possibly including wrench faulting, marginal to the Indian Craton ("marginal fracture basin"; DOLAN et al. 1987). This development was accompanied by extensive basalt volcanism in the Late Cretaceous, the Deccan Trap of northwest India (see Chapter 4.2) which reached into the Sindh area of southeast Pakistan. Towards the end of the Late Cretaceous, the detached Indo-Pakistan Plate began its rapid northward drift; the central Iran and Afghanistan Plates were now sutured to the southern margins of the Turan and Tarim Blocks (Figs. 6.5, 5.1).

In the West Pakistan Foldbelt, rocks of different palaeogeographic origins and ages are in juxtaposition. During the pre-Eocene period they were separated by the Neo-Tethyan ocean which was continuously consumed at the southern margin of the Eurasian Plate since the Late Cretaceous.

Following the regional tectonic model for the West Pakistan Foldbelt by BANNERT et al. 1992, the palaeogeographic and geodynamic impact of the Plate collision between the Indo-Pakistan Plate and the southern margin of the Eurasian Plate is discussed (see also Chapter 6.33). During the Late Cretaceous, the northern part of the Indo-Pakistan Plate began to cross the equator (Fig. 6.9). Mostly pelagic limestones of the Parh Group were deposited, with local intercalations of deltaic to fluviatile Pab Sandstone. The pelagic sediments also covered parts of the oceanic seafloor (Bela-Waziristan Ophiolite Zone). Initial tectonic deformation of the Bela-Waziristan Ophiolite Zone must have occurred before or during the deposition of the Parh Group sediments. An angular disconformity exists between Jurassic sediments and the overlying Parh Group. On the Hazara Block of the Indo-Pakistan Plate, shallow water sediments were deposited.

6.3 Cenozoic

During the Cenozoic, the palaeogeographic and geodynamic evolution was, and still is, governed by the collision of the Arabian, the Indo-Pakistan and Eurasian Plates. Because of the different geological evidence of the collision in the Indus Basin, in the West Pakistan Foldbelt and in the Himalayas, these regions are discussed separately.

6.31 Cenozoic of the Indus Basin

At the end of the Cretaceous, the eastern flank of the Lower, and parts of the Upper Indus Basin were uplifted by epeirogenic movements, and parts of, or the entire, Jurassic and Cretaceous sequences of the uplifted region were eroded. In the southeast, uplift and erosion were accompanied by the Deccan trap volcanism. The basal members of the **Paleocene** sequences (Khadro Formation) of the Lower Indus Basin include these volcanics and their erosion products. The depositional pattern then changed to a marine transgressive phase and the edge of the Basin shifted to the east as compared with the pre-Tertiary sediments. The entire basin developed a much more complex structure than previously existed, with a number of sub-basins, and areas of shallow marine deposition or non-deposition (Bara Formation with coal, and Lakhra Formation in the Kirthar Foredeep; Khadro and Dungan Formations in the Sulaiman Foredeep). In the Upper Indus Basin, sandy sequences were laid down where the transgression occupied new regions east and south of the Cretaceous edge of the Basin (Hangu Formation), followed by dominantly limestone (Lockhart Formation), and shale, marl and sandstone (Patala Formation) of shelf depositional environment.

During Early **Eocene**, the transgression covered additional areas of the Indian Craton to the east, whereas, during Late Eocene, a phase of regression is indicated by the depositional pattern. In the Lower Indus Basin, sedimentation was dominated by carbonates in the east (Laki/Kirthar Formations), and by shale in the west (Ghazij/Kirthar Formations). However, this simplified scheme was influenced and partly changed by further development of the structures within the Basin. In the Upper Indus Basin, mainly limestone, shale and minor sandstone and conglomerate were laid down (Panuba, Sakesar, Kuldana, Kirthar (lower part) Formations) during a period of complex sub-basin development with numerous discrete depocentres (Fig. 6.10).

Apparently, the Basin became progressively more segmented toward the north, where, during Eocene, the last stage of Basin development commenced. This phenomenon reflects the approaching impact of the plate collision, starting in the south during the Paleocene, and progressing towards north. The Indian Craton and the Afghanistan "Blocks" might have been already welded together in Late Eocene, allowing the marine carbonate sedimentation to continue further west across the sutures. The sequences may thus have been linked with their time equivalents (in Afghanistan described by WOLFART & WITTEKINDT 1980).

Marine **Oligocene** sedimentation was restricted to the southern part of the Lower Indus Basin (Nari Formation, Momani Group), and to parts of the sub-basins within the Upper Indus Basin. Uplift and erosion were widespread resulting in strong influx of

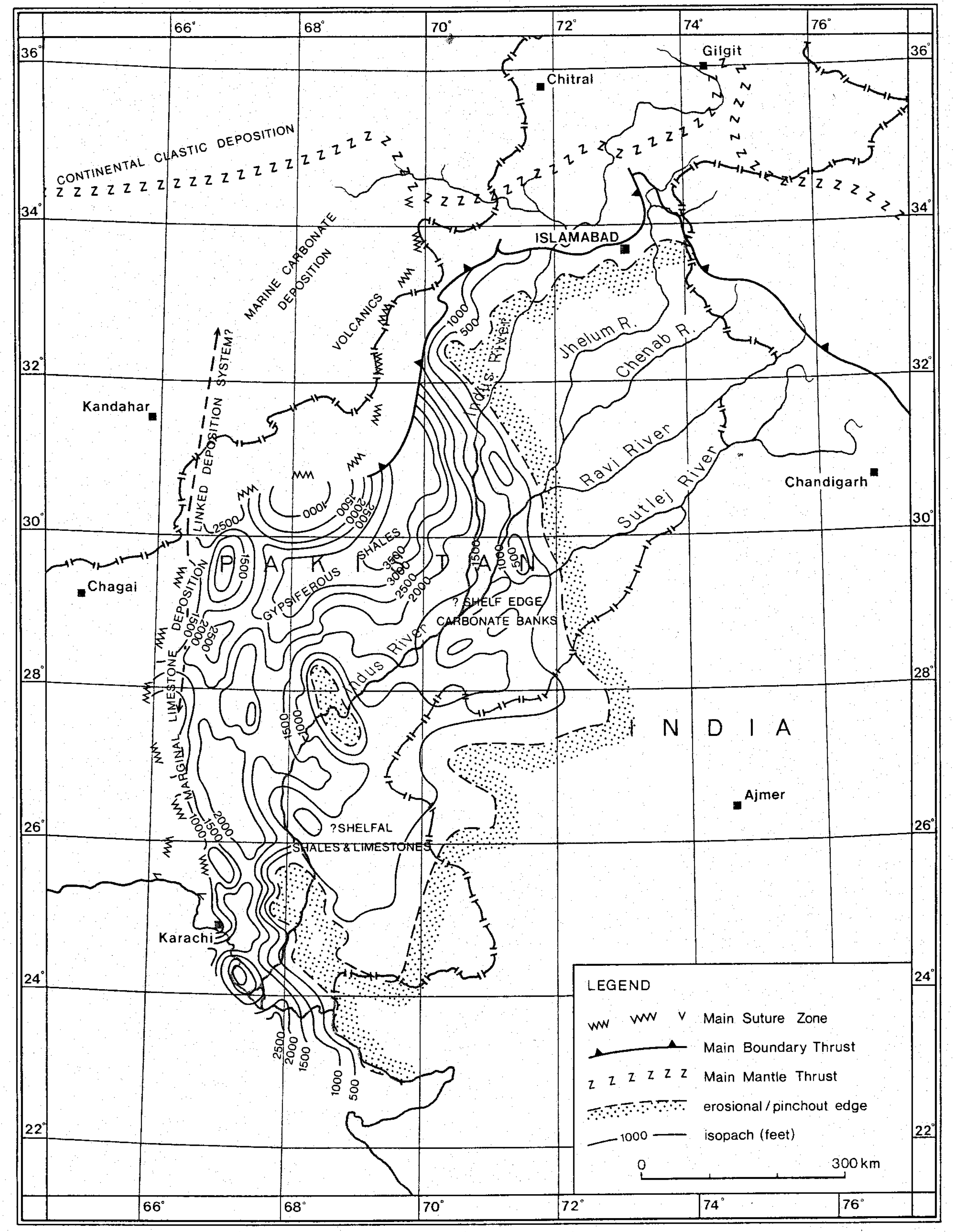


Fig. 6.10. Middle and Late Eocene depositional patterns (after DOLAN et al. 1987, fig. 59).

clastics, particulary from the raising topography of the West Pakistan Foldbelt region and of the Himalayas. Deposition in general became increasingly terrestrial.

Marine sedimentation continued during **Miocene** in the Lower Indus Basin (Gaj and Nagri Formations), dominantly of sandstone and shale, with minor limestone in the Gaj, and clay and conglomerate in the Nagri Formation. Some estuarine-fluviatile beds indicate the transition into the Siwalik Group (Nagri, Dhok Pathan, Soan Formations) during Late Miocene and **Pliocene** times. The marine depositional environment retreated entirely to the present zone of coast lines during the **Quaternary**, while the accumulation of huge masses of fluviatile pelites and clastics exceeded the rate of subsidence.

A major period of structural deformation commenced during Miocene and reached its maximum in Middle Pliocene between 4.5 and 3.5 million years ago. During the Pliocene and Pleistocene, between 2.1 and 1.6 million years ago, a second phase of intense deformation occurred which weakened in Late Pleistocene. In the foreland east of, and within the West Pakistan Foldbelt, and south of the rising Himalayas, enormous amounts of molasse type clastics accumulated in Miocene (Chinji Formation), Pliocene (Nagri, Dhok Pathan, Soan, Gawadar Formations), **Pleistocene** (Jiwani, Haro, Bostan, Lei Formations), and in **Holocene**. Deformation still continues, mainly related to the continuing stresses between the Indo-Pakistan, the Arabian and the Eurasian Plates.

6.32 Cretaceous and Cenozoic of the Himalayas

During Late **Cretaceous**, detached microplates of Gondwana began to be sutured to the blocks of central Iran and Afghanistan. In the region of the Himalayas and Trans-Himalayas north of the Main Karakorum Thrust (MKT; Fig. 2.4), Late Cretaceous shelf sediments of the passive continental margin of the Indo-Pakistan Plate were deposited, uplifted in the Trans-Himalayas and partly eroded. The Kohistan Island Arc Complex (see Chapter 2.253) became accreted to the Karakorum microplate north of it (SEARLE et al. 1987). The collision zone is marked by the MKT (or "Northern Suture") which passes to the southeast and east into the Indus-Tsangpo Suture (Figs. 2.3, 2.4). The extensive Karakorum granitoid batholith north of the suture formed prior to the continental collision, about 95 mio years ago (LEFORT et al. 1983).

The Kohistan Island Arc Complex is bordered to the south by the Main Mantle Thrust (MMT; Fig. 2.24). It consists of Paleozoic sediments intruded by porphyries and quartz diorites which were covered by mainly platform carbonates of Mesozoic age, accompanied by Jurassic to Upper Cretaceous tholeiitic to andesitic volcanic rocks and volcanoclastic sediments. The platform carbonates indicate stable shelf conditions until initial collision with the Karakorum microplate (TAHIRKHELI & JAN 1979, TALENT et al. 1982, MALINCONICO 1986, SEARLE et al. 1987). Granitoid rocks intruded the already folded sequences of the island arc complex, about 50 mio years ago (SEARLE 1989). The Kohistan Batholith (Fig. 2.4) was formed during Cenomanian to Late Eocene (PETERSON & WINDLEY 1985), a time span remarkably consistent with ages derived also from other plutonic rocks north of the MMT (SEARLE et al. 1987, SEARLE 1989). The extensive (>350 km long, and up to 45 km wide, about 8 km thick) Chilas Complex of layered norites, gabbros, hypersthene gabbros and dunites was considered by SEARLE et al. (1987) as the magma chamber for the Kohistan Island Arc Complex being probably the largest exposed in the world (COWARD et al. 1988). At the southern edge of the Kohistan Arc, ultramafites intruded a tectonic wedge of garnet granulites in the Jijal rock complex (JAN & HOWIE 1981; Fig. 2.4). Origin and age relationships of both units are still uncertain. As SEARLE et al. (1987) considered, they may belong to a distinct arc accreted to the southern margin of the Kohistan terrane.

Between the Kohistan Batholith-Chilas Complex and the Jijal Complex there are zones of intensively deformed amphibolites and metasediments with $^{39}Ar/^{40}Ar$ ages on hornblendes of older than 75 mio years (SEARLE et al. 1987, COWARD et al. 1987).

Large folding affected the Kohistan Island Arc sequences including the MMT at their base, thus forming NNE trending antiforms, e.g. the Nanga Parbat Syntaxis, where large scale warping still continues (OWEN 1989). Along the crestal areas of the folds, the island arc sequences were partly or completely eroded away.

During **Paleocene** and **Eocene**, Neo-Tethyan shelf sediments continued to accumulate at the passive continental margin of the Indo-Pakistan Plate. In the Indus Basin south of the Main Boundary Thrust (MBT), these sediments were deposited in various sub-basins, which formed as a result of further northward migration of the Plate (Fig. 6.9). The Basin segmentation, which started during Paleocene in the Lower Indus Basin and progressed to the north during Eocene, probably continued further northwards and beyond the MBT in the region of the Himalayas. However there is not enough stratigraphic evidence as yet for reconstruction of sub-basin developments.

All post-Eocene sediments of the Pakistan Himalayas are of terrestrial origin and reflect the rising topography which is in turn governed by the collisional events between the plates.

As outlined by COWARD (1986), PATRIAT & ACHACHE (1986) and TRELOAR (1989), the Indo-Pakistan Plate began to enter the subduction system about 55 to 50 years ago, during Eocene time, establishing actual collision (the "kink") at about 40 mio years ago in Late Eocene. This period of time coincides with the termination of calcalkaline intrusions in northern Kohistan. The rate of migration of the plate dropped from 10 cm/year to 5 cm/year, and continued at the rate of 5 cm/year during collision (MOLNAR & TRAPPONIER 1975).

Since then there has been between 1,200 km and 2,000 km of convergence between the both Plates, out of which two thirds was accomodated by crustal shortening in Tibet, and one third by thrusting in the Himalayas to the south of the Main Mantle Thrust (BUTLER & PRIOR 1988). This shortening was caused by the development of a wide range of imbricated thrusts mainly in the sedimentary cover sequences of the Indo-Pakistan Plate. In as much crustal basement was generally not involved, the sedimentary sequences were apparently decoupled from the basement and thus underwent considerable thickening due to stacking of thrust piles at higher levels of the Plate (TRELOAR 1989).

In general, deformation spread southward from the Northern Suture, involving the Kohistan Island Arc Complex which became accreted to the Karakorum microplate in Late Cretaceous (Figs. 2.3, 2.4). Barrovian metamorphism, migmatization and generation of Oligocene-Miocene leucogranites were accompanied by south-verging recumbent nappes inverting metamorphic isograds (SEARLE et al. 1987, WILLIAMS 1989, TRELOAR 1989).

The Karakorum (including the Kohistan Island Arc Complex)–Nanga Parbat Himalayas are one of the most rapidly rising mountain areas in the world, with Quaternary and Holocene uplift rates averaging at 2 mm/year (ZEITLER 1985, COWARD et al. 1987, OWEN 1989). Uplift in excess of 2 mm/year is centred around the Nanga Parbat-Haramosh Massif and is caused by large scale regional warping of the Nanga Parbat Syntaxis whereby associated faults (e. g. Rakhiot Fault; Fig. 2.4) are considered to be neo-tectonic expressions of the rapid uplift (OWEN 1989).

Erosion products of the rising Himalayas, including **Oligocene, Miocene, Pliocene** and **Quaternary** molasse sequences, accumulated in the subsiding forelands; Pleistocene and Holocene sediments also accumulated in a number of basins within the Himalayas, some of which have valley fills in excess of 500 m consisting of debris-flow, tills, fluvial, glaciofluvial and lacustrine deposits (OWEN 1989). All these sediments were and are included in the ongoing deformation processes. Pleistocene sequences of the Siwalik Group were folded and faulted, and Holocene deformation is indicated by deflecting of streams, and by seismicity along active faults. As observed by OWEN (1989), however, many of the thrusting, faulting and folding phenomena visible in Quaternary sediments of the Himalayas were not caused by neotectonic deformation, but by processes in the glacial depositional environment, debris-flow, and sliding of sediments down palaeoslopes.

6.33 Cenozoic of the West Pakistan Foldbelt

(DIETRICH BANNERT)

A different evolution during the Cenozoic is observed in the region of the West Pakistan Foldbelt (see Chapter 2.23). Its geological setting is shown on Figs. 5.6, 5.7, 5.8, geol. maps, the palaeogeographic history of the Chagai-Ras Koh-Mirjawa area is shown on Fig. 6.11. The region of the West Pakistan Foldbelt has been discussed recently by BANNERT et al. (1992).

After the first deformation during Late Cretaceous, a second one took place in the **Paleocene** of the Bela-Waziristan Ophiolite Zone when the ophiolitic seafloor material in the Bela, Muslimbagh and Waziristan areas was obducted onto the Khuzdar Block of the continental Indo-Pakistan Plate. It was the beginning of the continent to continent collision of the Indo-Pakistan Plate with the Eurasian Plate (Afghan Block), which led to an anticlockwise rotation of the former. The Khuzdar Block during this time was the leading edge of the Indo-Pakistan Plate, and its Mesozoic sediments were folded and most likely detached from the basement of the Indian Shield. During the progress of the collision, the Bela and Muslimbagh ophiolites were thrust on the Mesozoic sediments of the Bela-Waziristan Ophiolite Zone. Their erosional debris was deposited on the Mesozoic sediments of the Khuzdar Block adjacent to the east (Paleogene Gidar Dhor and Jamburo formations) which contain exotic blocks partly of ophiolitic nature in several layers.

The original fold trend of the Mesozoic sediments of the Khuzdar Block was not the NNW trend as observed today. There are numerous indications of an additional anticlockwise rotation of the Khuzdar Block during the progress of collision. Therefore, an initial oblique collision might be postulated. Rocks of the Eocene Kharan Formation

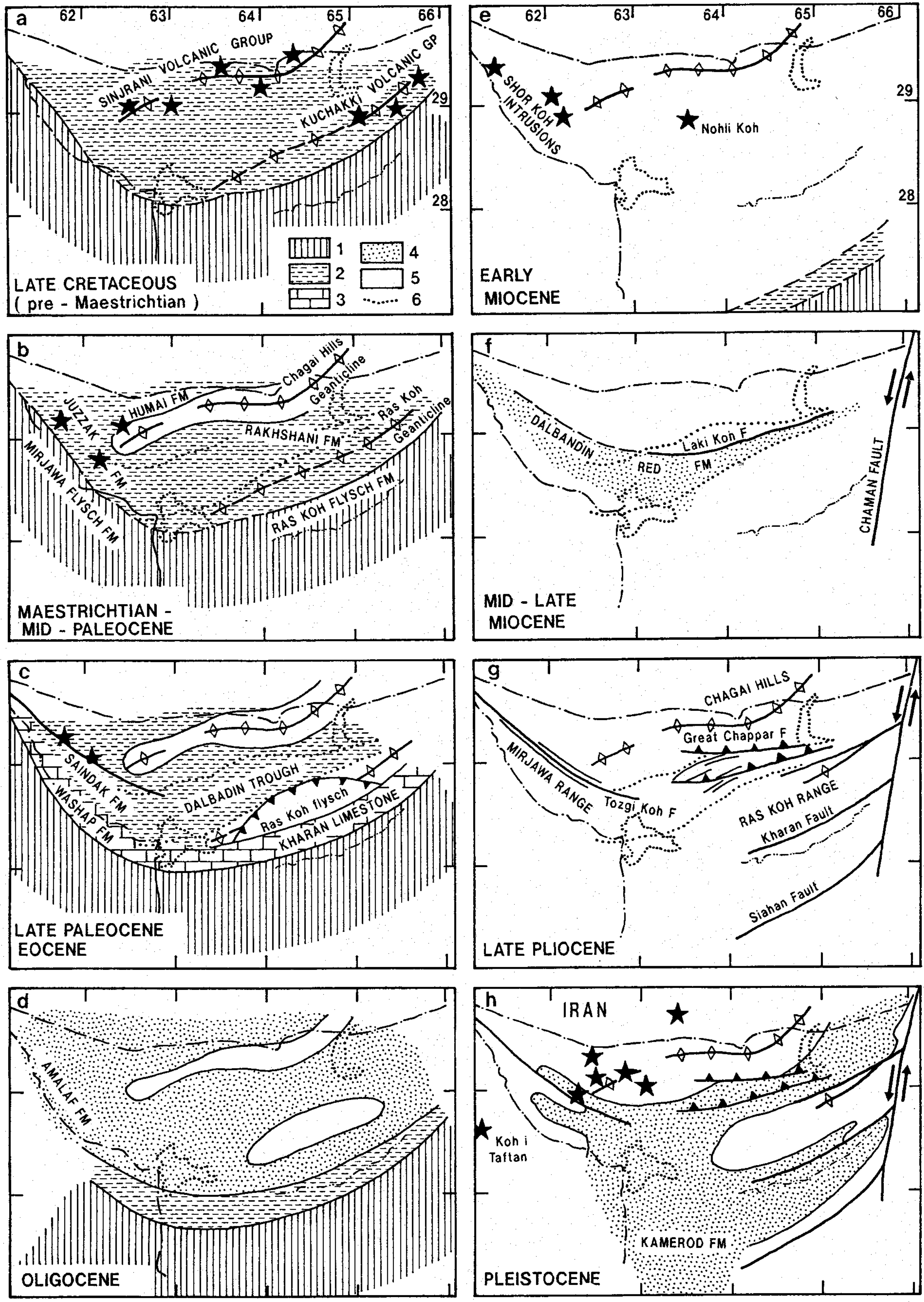


Fig. 6.11. Palaeogeographical history of Chagai – Ras Koh – Mirjawa area (1) flysch sediments (2) marine sediments/volcanics of forearc (3) shallow water limestones (4) coastal plain/continental sediments (5) undifferentiated and erosional areas (6) limits of Dalbandin Trough. Stars indicate volcanoes (after ARTHURTON et al. 1982, fig. 3).

are incorporated into the Chaman Fault zone indicating a post-Eocene age for at least part of the fault. This in turn leads to the conclusion, that the structures along the southern margin of the Eurasian Plate remained in their original east-west to southwest-northeast orientation until the end of Eocene. Consequently, the trend of the fold axes on the Khuzdar Block would have had a northeast orientation during the first folding. The opening of the Kirthar Basement Fault (Fig. 2.2) enabled the Indo-Pakistan Plate to the east of the Khuzdar Block to continue northward undergoing an anticlockwise rotation. The movement of the Khuzdar Block slowed down as the result of the initial collision and began to rotate in a faster rate than the rest of the Indo-Pakistan Plate.

During the **Eocene**, the shallow water Kirthar Limestone in the east of the Khuzdar Block and the coeval shallow water limestone of the Spintangi Formation in the Quetta area, were deposited. The space for the further rotation became narrow between the Sulaiman Basement Fault and the Bela-Waziristan Ophiolite Zone which also was rotated together with the Khojak Flysch Belt and the Khuzdar Block (see Chapters 2.21 through 2.23). Consequently, as a further stage of the folding, a back thrusting affected the northwest part and the central part of the Khuzdar Block. It led to the eastward thrusting of the Kalat Plateau and the westward thrusting of the Kirthar Thrust Sheets with a passive roof-thrust developing in the Eocene Ghazij Shale. The final stage of the tectonics involving the Khuzdar Block is an internal northward thrusting. It affected the Miocene Nal Limestone overlying the Bela Ophiolites as well as the Mesozoic sediments in the area south of Khuzdar. The Spintangi Limestone of the Kalat Plateau revealed also northwest-trending sinistral strike-slip faults indicating a young northward directed compression in this area (Fig. 2.5).

After the opening of the Kirthar Basement Fault, the Sulaiman Block to the east continued its northward movement together with the larger part of the Indo-Pakistan Plate. It collided during the **Oligocene** with the Afghan Block. It bend downwards to the north during underthrusting along the former subduction zone. The underthrust led to the detachment of the overlying Mesozoic and Cenozoic sediments. They were folded and piled on each other in large thrust lobes (Fig. 2.5) forming the nappes of the Marri-Bugti Hills and Sulaiman Ranges. In the north, parts of the adjacent Bela-Waziristan Ophiolite Zone were also incorporated in the Muslimbagh-Zarra Nappe and Loralai Nappe. The northward bending of the Sulaiman Block generated a foredeep (Urak-Sibi Trough) in which huge amounts of erosional debris in conglomeratic molasse facies accumulated that reached a thickness of 7,000 m.

During the southward propagating of the Marri-Bugti/Sulaiman nappes, the basement of the Urak-Sibi Trough detached along a passive roof-thrust in the underlying Eocene Ghazij Shale under which the nappes could move southward. The Urak-Sibi Trough was elevated, where, in the Zarghun Syncline, its core forms today the highest mountain in Baluchistan (Mt. Zarghun 3,562 m). The nappes become younger towards south; there, the Urak-Sibi Conglomerate as well as the younger Dada Conglomerate are incorporated into the frontal nappes.

The northward bending of the Sulaiman Block led to the Sulaiman Basement Fault which assumed a downthrow to the west. It formed a considerable obstacle during the advance of the Marri-Bugti/Sulaiman nappes. At their eastern fringe they were hampered in their southward movement. Considerable friction as well as a back-lagging resulted. Finally, the advance came to an end when the individual horses of the nappes jammed against the step of the Sulaiman Basement Fault thus forming the Sulaiman Anticlinorium. The advance of the nappes, however, continued. This was facilitated by the development of the western Sulaiman Transform Fault west of the Sulaiman Range. The sinistral displacement along this fault exceeds 27 km by far. More recently, volcanism developed forming the Kohlu volcanoes of the Marri-Bugti Hills.

East of the Sulaiman Basement Fault, the remaining Indo-Pakistan Plate continued to move northward. The next segment, the Hazara Block, collided in a "head-on fashion" with the western Himalaya. The precise age of this collision is not yet firmly established.

The molasse sedimentation commenced during the Miocene and continued during **Pliocene** and **Quaternary** times and continues today. The sediments of the Indo-Pakistan Plate detached and were thrust in several thrust-sheets towards the south forming the Hazara Arc. The Murree Fault in the south is thrust over the molasse sediments of the Kohat-Potwar Plateau. Under the thrust, an imbricate stack of thrusted folds developed which contain hydrocarbon bearing structures of the Potwar area (see Chapter 7.1; Fig. 2.4).

The Paleozoic through Recent sediments south of these stacks decoupled in the evaporites of the underlying Eocambrian Salt Range Formation. It enabled the continuous northward motion of the Indo-Pakistan Plate under the decoupled sediments of the Kohat-Potwar Plateau. A north-facing step fault (striking west-east) within the basement of the Indo-Pakistan Plate approached the decoupled sediments, causing a ramping and, consequently, a southward thrusting of the Salt Range with an estimated overlap of 19 km - 23 km (LILLIE et al. 1987). To the east, the southward moving Potwar Plateau collided with the southwestward moving, frontal folds of the western Himalaya thus forming the Jhelum Re-entrant (Fig. 7.2). A domal uplifting of the rocks is assumed in the northern Jhelum Re-entrant by BOSSART et al. (1988). The Main Boundary Thrust forms the frame for the Jhelum Re-entrant in the north and east. In the west, the Main Boundary Thrust might be represented by a sinistral strike-slip fault. This strike-slip fault forms the eastern boundary of the Hazara Arc. The Jhelum Re-entrant is above the Jhelum Basement Fault, east of which the main part of the Indo-Pakistan Plate continues to move northward as one block. The segmentation of the Indo-Pakistan Plate thus was restricted to the western part of the collision zone where the collision took place in an oblique fashion.

7. Energy resources

Domestic energy resources satisfy 69 % of Pakistan's commercial energy requirements, with natural gas supplying 39 %, hydroelectric power 15 %, oil 10 % and coal 5 %, the remaining requirements are met mostly by imported oil (RAZA et al. 1992). Because of the fast growing demand, considerable effort has been made in the field of energy resources development and substantial results have been achieved. Exploration has contributed significantly to both a better understanding of the geology of the country and self reliance in energy resources.

7.1 Hydrocarbons

(HILAL A. RAZA and FRIEDRICH K. BENDER)

Oil exploration drilling started in 1866 near Kundal (32° 32'N; 71° 18'E) in the Upper Indus Basin, in the Kohat-Potwar Foredeep. Between 1885 and 1892, a total of about 3,400 t of oil were produced, near Khattan (29° 34'N; 68° 28'E) east of Sibi in Baluchistan. From 1915 to 1947, when Pakistan became independent, four oil fields were found in the Kohat-Potwar Foredeep: Khaur (33° 15'N; 72° 27'E) (1915; 0.6 mio t of recoverable oil reserves), Dhulian (33° 12'N; 72° 21'E) (1935; 5.5 mio t), Joya Mair (32° 59'N; 72° 46'E) (1944; 1.4 mio t), and Balkassar (32° 56' 38"N; 72° 39' 52"E) (1946; 4.3 mio t). The discovery of the giant Sui (28° 38' 30"N; 69° 12' 21"E) gas field (1952; 250 billion m^3 reserves) by Pakistan Petrol. Ltd. triggered intensive exploration in the Lower Indus Basin. This resulted in additional discoveries (recoverable reserves in billion m^3): Zin (28° 56' 10"N; 68° 43' 43"E) (1954; 2.8), Uch (28° 38' 30"N; 68° 37' 15"E) (1955; 116), Khairpur (27° 30'N; 68° 47'E) (1955; 28.3), Mari (27° 56' 35"N; 69° 45' 40"E) (1957; 180), Kandhkot (28° 11'N; 69° 13'E) (1959; 22.5), and Mazarani (27° 40' 31"N; 67° 30' 27"E) (1959; "small"). After the foundation of the state-owned Oil and Gas Development Corporation (OGDC) in 1961, numerous hydrocarbon discoveries resulted from further intensified exploration activities by OGDC as well as private companies. Important discoveries were the oilfields Toot (33° 09' 33"N; 72° 02' 30"E) (1968; 2.1 mio t reserves), and Meyal (33° 18'N; 72° 10'E) (1968; 6.6 mio t), both in the Kohat-Potwar Foredeep. The discovery of the Khaskeli (24° 48' 35"N; 68° 34' 14"E) oil field (1981; 1.1 mio t reserves) in the Lower Indus Basin opened up new prospects. This was the 24th hydrocarbon discovery (10th for oil) in a period of 70 years of exploratory work. In the following 13 years, 71 hydrocarbon discoveries (39 oil, 32 gas) were made of which 61 were in the Lower Indus Basin.

In the Kohat-Potwar Foredeep, systematic exploration continued as well, and resulted in some further discoveries: Adhi (33° 08'N; 73° 09'E) (1978; oil and gas), Dakhni (33° 24' 70"N; 71° 56' 45"E) (1983; gas and condensate), Dhurnal (33° 20' 19"N; 72° 35' 29"E) (1984; oil), and Chak Naurang (32° 59' 31"N; 72° 55' 37"E) (1986; oil). Offshore exploratory wells (10) did not encounter exploitable hydrocarbon reserves as yet.

Estimates on the hydrocarbon potential of Pakistan range between 5 billion t to 7 billion t oil and about 5,700 billion m^3 gas. The proven reserves are 67 mio t oil and 890 billion Nm^3 gas. In 1993, oil production was 3.0 mio t, gas production 16 billion m^3 (Data sources: DOLAN et al. 1987, RAZA & SHEIKH 1988, Bundesanstalt für Geowissenschaften und Rohstoffe 1988, RAZA & AHMED 1990, Erdöl, Erdgas, Kohle 1991, HILLER 1994, Hydrocarbon Development Institute of Pakistan 1994).

7.11 Basin definition

The definition of basin configurations is complicated because their margins have shifted considerably during geologic history (see Chapters 5, 6), and they partly overlap each other as a result of tectonic displacements (see Chapter 5). Moreover, basins have been outlined and named differently in various publications and unpublished reports. Fig. 7.1 shows a simplified picture of basin margins and terms currently in use by the Hydrocarbon Development Institute of Pakistan (HDIP), or used by QUADRI (1981), KAZMI & RANA (1982), DOLAN et al. (1987), RAZA & SHEIKH (1988) and HILLER (1993). They are defined as follows:

Indus Basin: All the area within Pakistan west of the margin of the Indian Shield (margin generalised according to Cambrian through Tertiary borders; Figs. 6.4, 6.5, 6.6, 6.7, and 6.9), and the sutures separating the Indo-Pakistan Plate from the Afghan Block to the west (Fig. 2.4).

Upper Indus Basin: The area south of the Main Boundary Thrust and north of the Sargodha High (swell) comprising the Kohat-Potwar Foredeep including the Bannu Depression ("Basin"; Fig. 2.6).

Lower Indus Basin, in its northern parts "Middle Indus Basin" by other authors: The area south of the Sargodha High between the margin of the Indian Shield to the east and the suture zones to the west. This includes (from north to south) the Sulaiman Foredeep, the Kirthar Foredeep, the Karachi Trough, and the Indus Delta and fan area east of the Murray Ridge and west of the Indian Shield margin.

Baluchistan region: All that area within Pakistan to the west of the suture zones.

Offshore region: Offshore area from the Kutch Basin in the east to the Iranian border in the west.

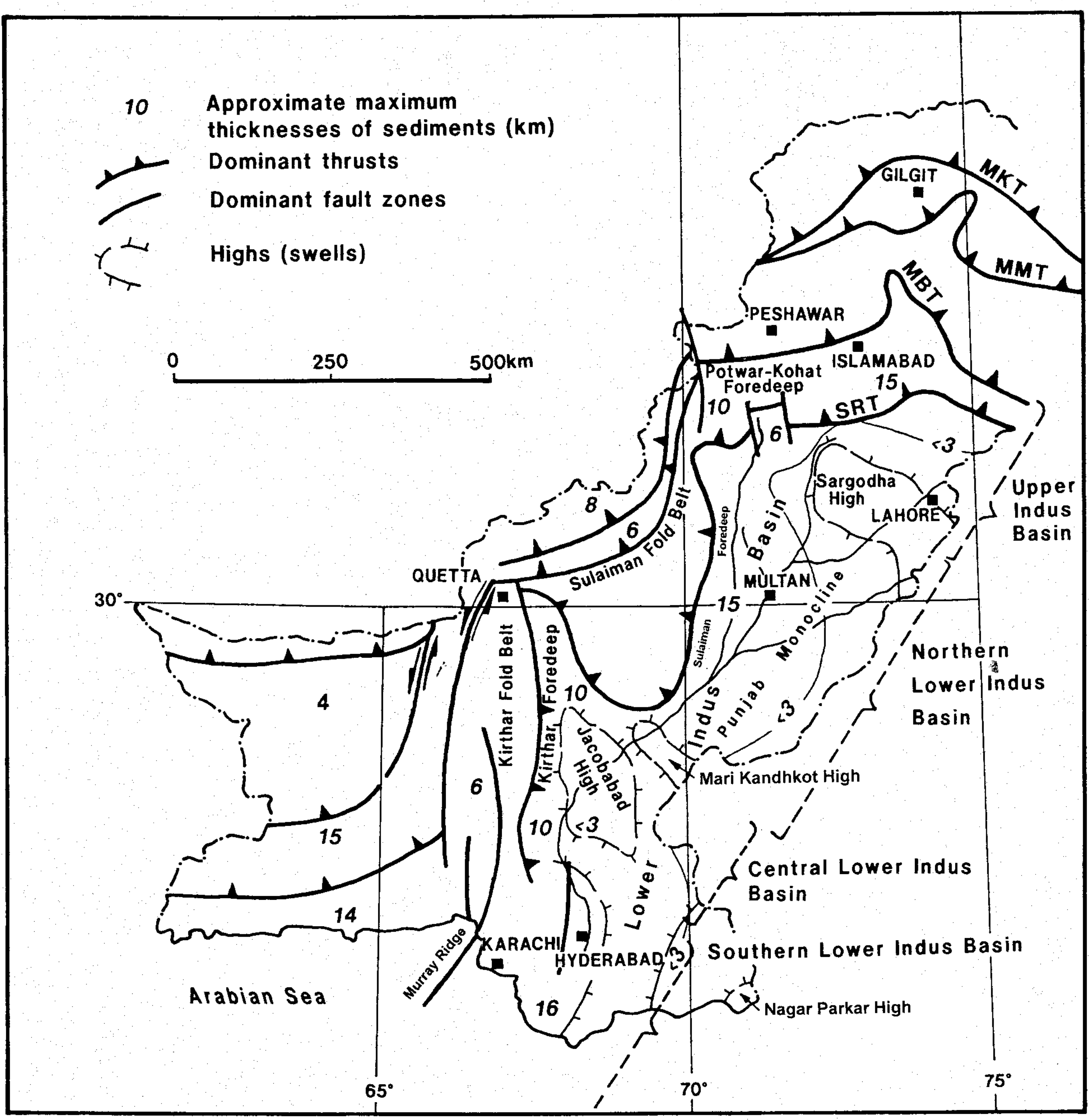


Fig. 7.1. Map of simplified basin margins in Pakistan (compiled and modified after KAZMI & RANA 1982, DOLAN et al. 1987, Hydrocarbon Development Institute of Pakistan 1992, HILLER 1994).

7.12 Kohat-Potwar Foredeep

The Kohat-Potwar Foredeep is commonly divided into a western part (Kohat-Sub-Basin) and an eastern part (Potwar-Sub-Basin) separated by the Mianwali Re-entrant. BANNERT (1987) and HILLER (1994) identified the following tectonic units: Kohat Fault Belt, Bannu Basin (Depression), Tank Re-entrant, Mianwali Re-entrant and Jhelum Re-entrant (Figs. 2.6, 7.2).

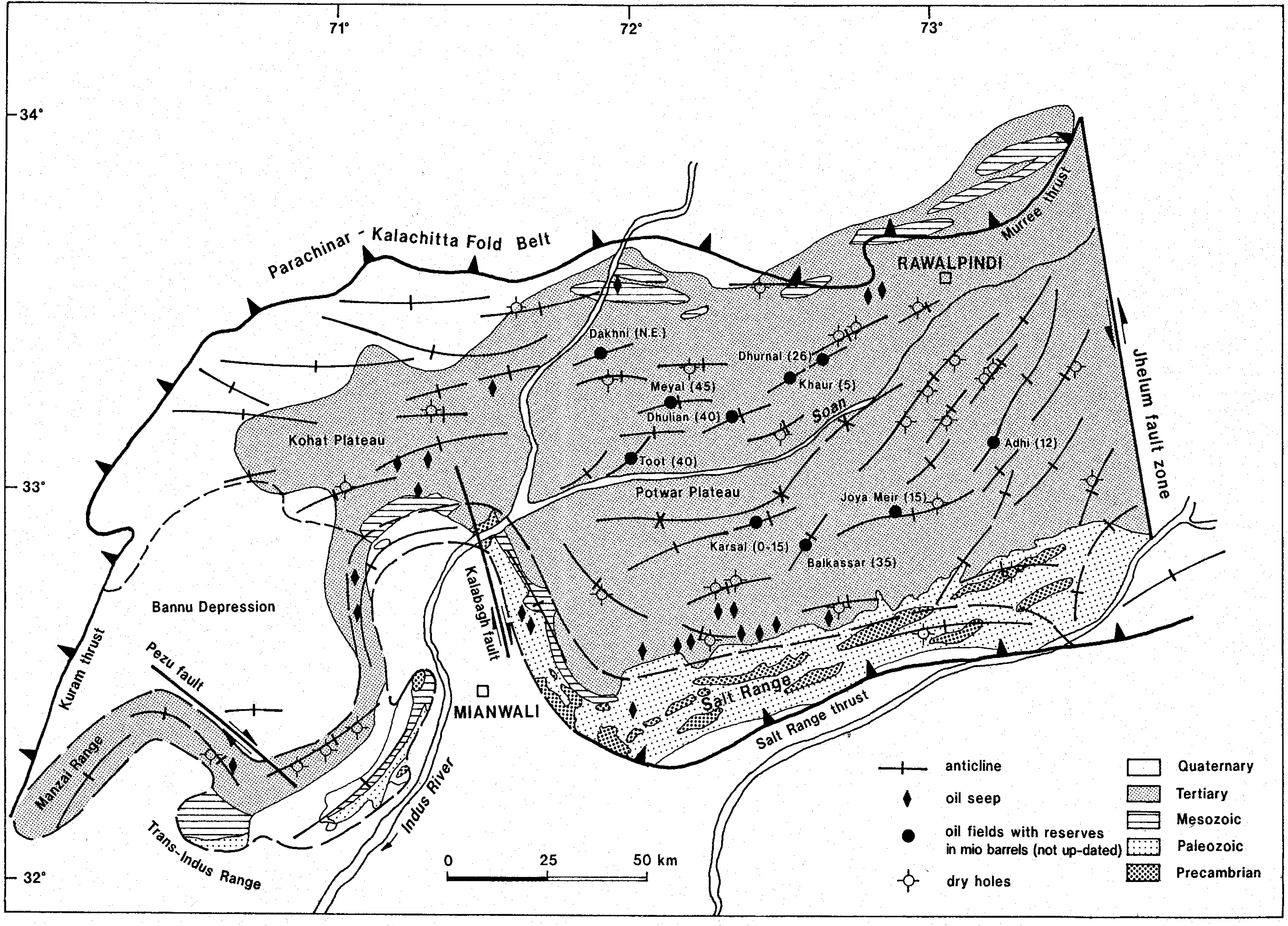


Fig. 7.2. Simplified oil-geological map of the Potwar-Kohat foredeep (after KHAN et al. 1986, HILLER 1994).

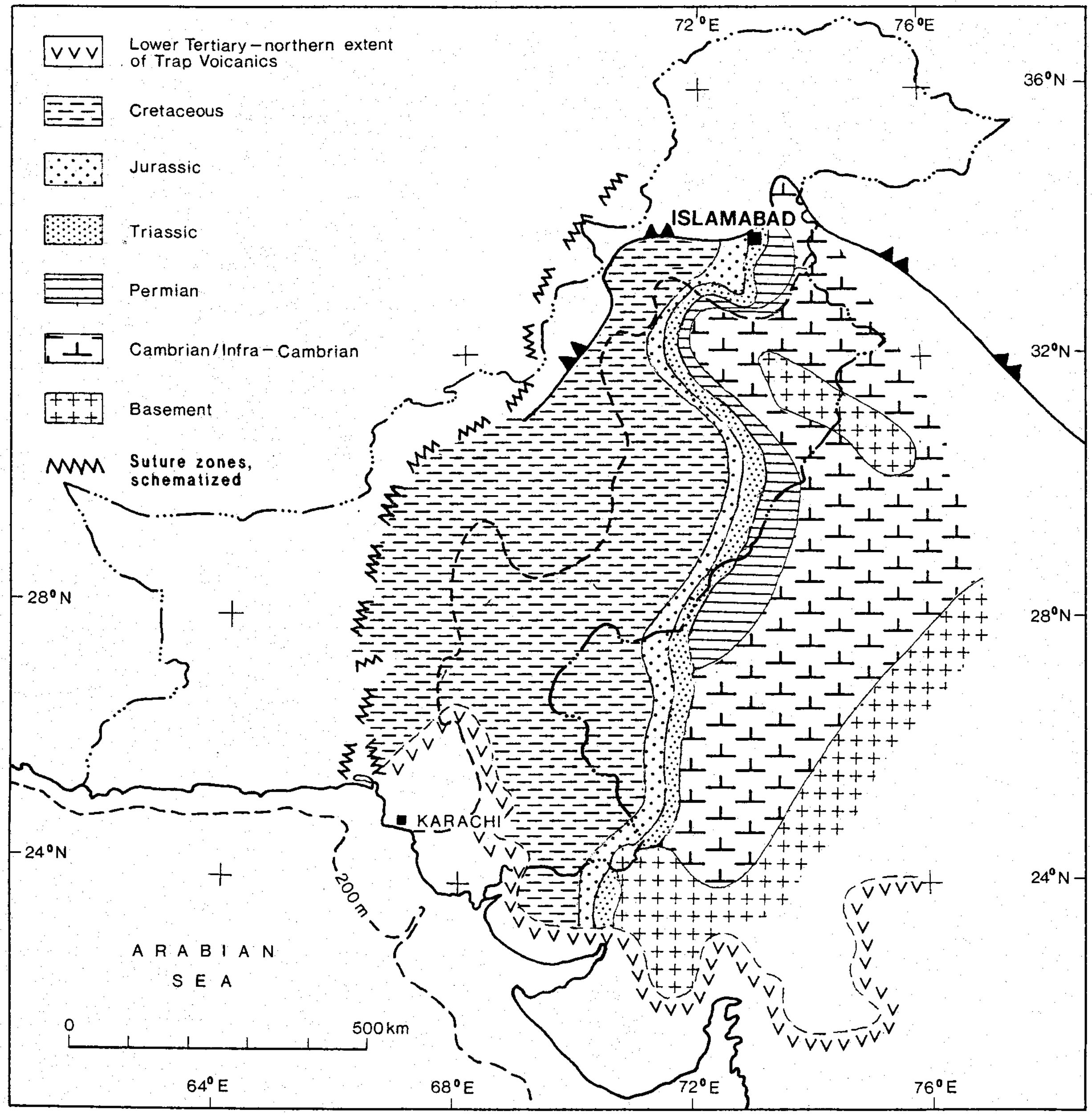


Fig. 7.3. Map of base Tertiary subcrop, Indus Basin (after DOLAN et al. 1987).

As a part of the foreland fold and thrust belt south of the Himalaya-Hindu Kush Ranges, its structural axis trends west to east (Fig. 7.2), but the basin axis from Cambrian to the base of Tertiary was generally south to north (Fig. 7.3). It is bordered in the north by the Main Boundary Thrust, in the south by the Salt Range Thrust. To the east, it ends at the transcurrent Jhelum fault system, to the west and northwest at the Sulaiman and associated transcurrent faults.

The **sedimentation, stratigraphic** details of the Phanerozoic sequence and the palaeogeographic-geodynamic evolution are discussed in Chapters 3 and 6.

Source rocks (see also Chapter 7.2; PORTH & RAZA 1990 a) are developed in the middle and upper part of the Precambrian-Cambrian Salt Range Formation with up to 36 % total organic content (TOC) and an oil yield of more than 20 % of rock weight. In the western Salt Range area, limited coal-bearing strata of Permian age and bituminous rocks of Triassic and Jurassic age are potential sources of hydrocarbons. Potential source rocks, containing coal beds, are widespread in the Upper Paleocene to Lower Eocene Patala Formation (average TOC above 1 %). In the southern Kohat and Bannu area, oil shales of the Lower Eocene Jatta Gypsum Formation (TOC up to 26.9 % and oil yield of about 20 % of rock weight) are potentially excellent sources, comparable with the Salt Range Formation.

The source rock **maturity** is mainly related to the geothermal gradients ranging between 1.5 °C and 2.6 °C/100 m (RAZA 1981), and the thickness of overburden. Conditions favourable for the formation and accumulation of the hydrocarbons (active oil window) are at depths ranging between 2,500 m and 5,000 m. This means that the most important source rocks of the Patala Formation reached the oil window during Pliocene, when the thickness of the Neogene sequence had approached its maximum. The major structural deformation in the Kohat-Potwar Fordeep developed also during Neogene, more or less simultaneously with the maturity processes. The migration of Palaeogene hydrocarbons could therefore have led to accumulations in suitable structural traps. Hydrocarbons generated earlier (e.g. Cambrian) could have been accumulated also in pre-Neogene structural traps.

Potential **reservoir rocks** in the Kohat-Potwar Foredeep are mainly clastics of Cambrian, Permian and Jurassic age, and carbonates of Eocene age (PORTH & RAZA 1990 a). The Cambrian Khewra Sandstone (net porosity 9 %–13 %) and the Tobra Formation of Permian age (matrix porosities between 10 % and 13 %) produce oil in the Adhi Field (eastern Potwar area). The Datta Formation of Jurassic age contains reservoirs that have porosities between 5 % and 18 % which are oil-productive in five fields. The most important reservoir rocks in the Foredeep are the Eocene carbonates (Chorgali and Sakesar limestones) with average primary porosities ranging from 2 % to 4 %, which developed secondary porosities of 15 % – 25 % as a result of dolomitization and fracturing along the crests of structures (MALIK et al. 1988).

Cap rocks are developed as shaly sequences in the Kussak Formation of Cambrian age, as intraformational shales within the Permian Dandot Formation, and in the Jurassic Datta Formation. In the southern Kohat area, the Lower Eocene evaporites (Bahadur Khel Salt) form excellent sealing cap rocks; the same applies to Eocene claystones (Kuldana Formation). The main sealing cover above the Eocene reservoir rocks is provided by claystones developed in the Miocene molasse sediments (Siwalik Group).

Almost all hydrocarbon accumulations that have been discovered in this foredeep are in **structural traps**. They consist mostly of anticlines and tilted blocks, generally bounded by faults or thrusts along their flanks. Salt intrusions resulting from halokinetic movements add to the trap possibilities (Fig. 7.4). Apart from the Permian Tobra Formation stratigraphic oil accumulation in the Adhi Field, further **stratigraphic traps** may exist but have not yet been investigated in detail.

Hydrocarbon prospects exist (for details: KHAN et al. 1986, RANKE & KAMRAN 1987, DOLAN et al. 1987, BANNERT 1987, PORTH & RAZA 1990 a, HILLER & AHMED 1989, HILLER 1994):

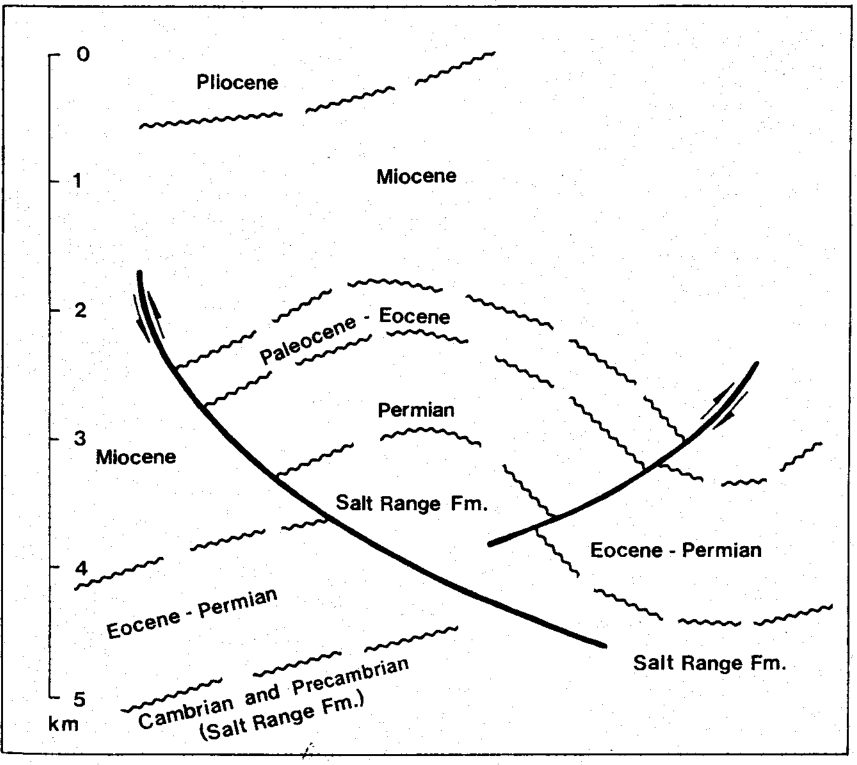


Fig. 7.4. Schematized cross-section of thrusted anticline with salt accumulation in the core, Upper Indus Basin (after ALTENKIRCH et al. 1987).

- In the Precambrian to Cambrian Salt Range Formation in the southeastern part of the Potwar area where the Khewra Formation sandstones are well developed; for example the Adhi Field produces high gravity oil;
- in the Lower Permian clastic reservoirs with oil production in the Dhurnal Field;
- in the Jurassic Datta Formation sandstones with oil production from the Dhulian, Meyal and Toot Fields;
- in the Paleocene reservoir rocks out of which the Dhulian and Dhurnal Fields produced oil;
- in the Lower Eocene carbonates (Sakesar Formation) which are the principal reservoir for oil and gas in the Potwar area.

Additional hydrocarbon prospects may exist in the Kohat-Potwar Foredeep, associated with thrusts. In the northern part, thrust sheets related to the Main Boundary Thrust advanced 10 km to 20 km southward over fold structures, as visualized by BANNERT (1987), which could provide targets for exploration. In the southeastern part of the Foredeep, HILLER & AHMAD (1989) described a northeast-trending subthrust sheet on the basis of reflection seismic interpretation by ALTENKIRCH et al. (1987). The sheet covers an area of about 330 km^2 as known so far. Thrusting caused a repetition of the oil prospective sequences from the top of the Eocene to the top of the Salt Range Formation, resulting from decollement within the salt.

7.13 Northern Lower Indus Basin and Sulaiman Foredeep

This region lies in the northern part of the Lower Indus Basin south of the Sargodha High (swell) and east of the sutures separating the Indo-Pakistan Plate from the Afghan Blocks. Toward the east, approaching the Indian Shield, the thickness of the sediments (depths to base Cretaceous) decreases from more than 5,000 m to less than 1,000 m (Punjab Monocline). In the south, the Mari Khandkot High (swell) separates the Sulaiman Foredeep from the Kirthar Foredeep (Figs. 7.1, 7.5).

Structurally, the area is dominated by the results of three tectonic events:

- Rifting during the Triassic which led, in the entire Lower Indus Basin (Fig. 6.6), to an interior fracture basin with steeply faulted margins and a horst-graben floor;
- collision of the Indo-Pakistan Plate with the Afghan blocks during Late Cretaceous and Palaeogene times which resulted in suturing, thrusting and faulting of the rock sequences of the West Pakistan Foldbelt (Fig. 2.1);
- post-collisional deformation of the Neogene-Quaternary sediments which accumulated in the Foredeep.

The structural axis of the Sulaiman Foredeep trends north-south and turns to the west and northwest with the southern Sulaiman Lobe into the Sibi Re-entrant (Fig. 7.5). The basin axis is north-south as shown on Fig. 7.3. The **stratigraphic** and **palaeogeographic development** are described in chapters 3 and 6. The main potential **source rocks** were defined in sequences within the following formations (PORTH & RAZA 1990 b):

- Samana Suk Formation (Middle Jurassic) with total organic matter (TOC) of max. 1.59 %;
- Sembar Formation (Lower Cretaceous) with TOC ranging between 0.52 % and 2.14 % in surface samples, and up to 4.33 % in core samples; in areas of moderate thermal maturity, the widespread source rocks in this formation are considered to have a very significant potential;
- Mughal Kot Formation (Upper Cretaceous) with TOC between 0.34 % and 0.56 %;
- Ghazij Group (Lower Eocene) with only 0.34 % TOC but containing coal (ca. 60 % TOC) as potential gas source rock;
- Kirthar Formation (Middle Eocene), Habib Rahi (average TOC 5.16 %) and Pirkoh Limestone (average TOC 3.72 %) members. The prebitumen with 50 % of the TOC comprises the dominant component of the organic matter; the oil yield reaches 6.5 % of the rock weight. Due to their wide areal distribution and thicknesses, these shales, marlstones and limestones of the Kirthar Formation are considered to be excellent potential source rocks.

Geothermal gradients as indicators for source rock **maturity** range between 1.12 °C to 1.71 °C/100 m in the area of the Punjab Monocline, and 4.1 °C/100 m in the southern Sulaiman Range (RAZA 1981, KHAN & RAZA 1986, PORTH & RAZA 1990 b). Vitrinite reflectance values are between 0.34 and 0.41 Rr in the Punjab Monocline; 0.85 to 0.93 Rr in a small zone bordering the Sulaiman Range to the east, and up to 3.43 Rr in the Sulaiman Range (PORTH & RAZA 1990 b). Palaeogeothermal and burial history studies show that the main potential source rocks have reached maturity for hydrocarbon generation in the entire northern Lower Indus Basin.

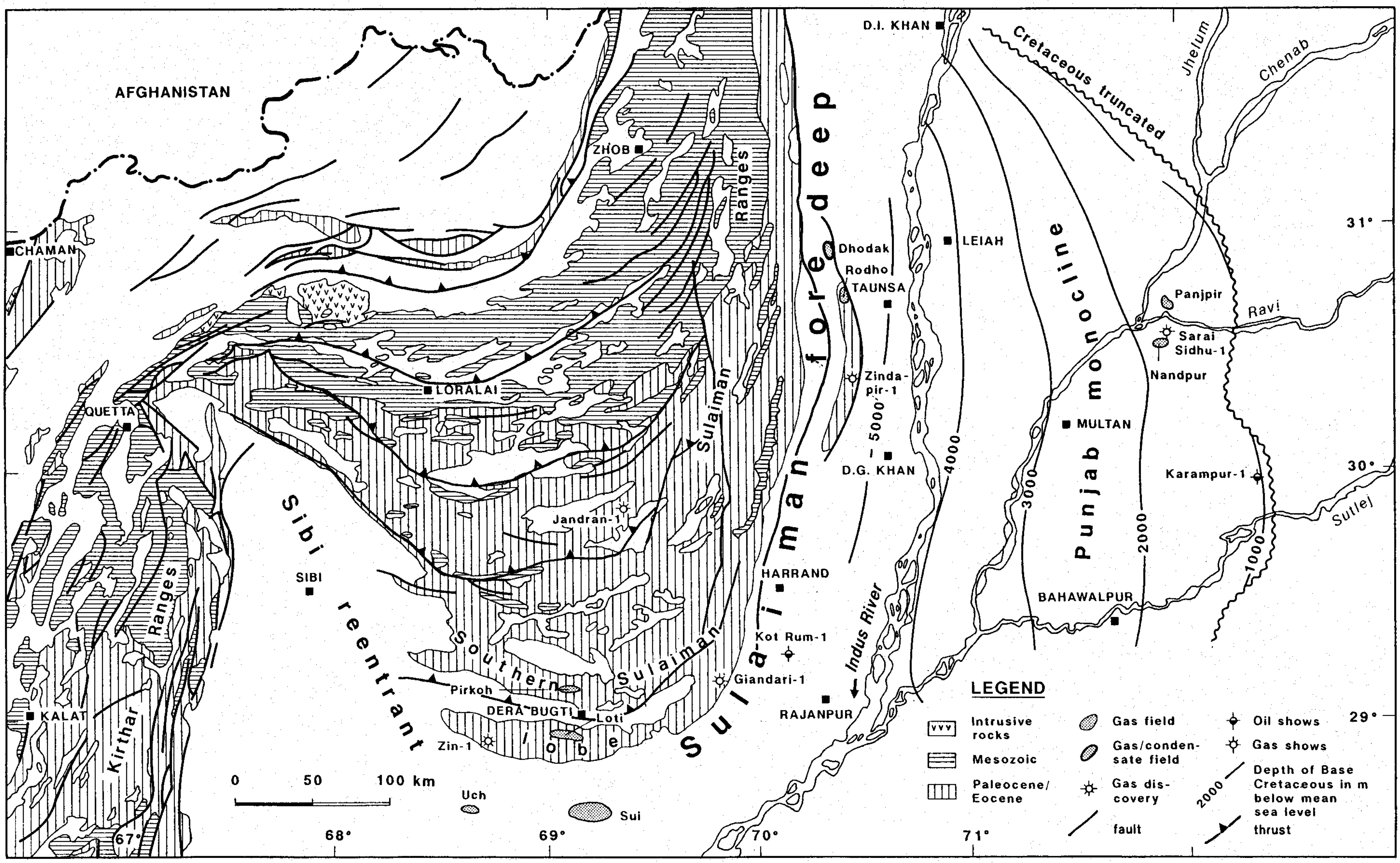


Fig. 7.5. Oil-geological map of Kirthar-Sulaiman Ranges and Punjab Monocline (modified after PORTH & RAZA 1990 b; Structure after BANNERT et al. 1992).

Potential **reservoir rocks** are present in the Khewra Formation of Cambrian age (porosities up to 21 %), in the clastics of the Lower Permian Nilawahan Group (up to 22 %), and in the Jurassic Datta Formation (15 % to 17 %; MALIK et al. 1988). Calcareous Sandstones of the Middle Jurassic Samana Suk and Chichali Formations (porosities 12 % to 17 %) and the Lower Cretaceous Lumshiwal Sandstone are potential reservoir rocks across the Punjab Monocline. Further clastics of good reservoir rock characteristics are observed in the Upper Cretaceous Mughal Kot Formation and the Pab Sandstone (gross thickness as much as 350 m, porosities between 7 % and 12 %). Gas occurs in the Pab Sandstone in the Dhodak (30° 52' 20"N; 70° 22' 39"E), Pir Koh (29° 08' 32"N; 69° 05' 37"E), Rhodo (30° 44' 26"N; 70° 26' 31"E) and Loti (28° 56' 08"N; 69° 04' 01"E) Fields. The Dungan Limestone of Late Paleocene age, and the Cretaceous and Eocene sandstone and carbonates represent the main gas reservoirs, especially, the Lower Eocene Sui Main Limestone (up to 665 m thick, average porosity 14 %), and the Sui Upper Limestone of Late Eocene age.

Effective **cap rocks** are shales within the Jurassic Samana Suk and Chichali Formations, in the Paleocene Ranikot Group, and in the Lower Eocene Ghazij Formation.

Four areas of different **structural** characteristics have been identified (AHMED et al. 1987, MALIK et al. 1988, PORTH & RAZA 1990 b):

- the structurally little affected area of the Punjab Monocline with only some insignificant faults and a few low-amplitude structures, probably induced by salt movements;
- the eastern area of the Sulaiman Foredeep with also little structural deformation;
- the areas along the eastern margin of the Sulaiman Range with the Zindapir Anticlinorium and along the southern Sulaiman Lobe (Marri Bugti Fold Belt). In the former area, the eastern flanks of north trending anticlines are bounded by reverse faults or overthrusts, with the Dhodak Condensate and Rhodo Gas Fields in culminations of the Zindapir Anticlinorium. In the southern Sulaiman Range, the gas fields Pirkoh and Loti and the major gas discovery at Uch are in east-west trending anticlines with steep northern and mostly thrust-controlled southern flanks. The giant Sui Gas Field produces from a broad anticline which extends about 50 km west to east. The gas-bearing area of the Sui Main Limestone is about 200 km^2 and the thickness of the gas column is 226 m;
- the central Sulaiman Fold Belt with very complex structures where potential source rocks are in parts post-mature and locally eroded.

Stratigraphic traps can be expected, particularly, where potential reservoir rocks are truncated by Mesozoic and Tertiary unconformities.

Possible targets for future hydrocarbon exploration include the following (DOLAN et al. 1987, PORTH & RAZA 1990 b, RAZA & AHMED 1990, HILLER & AHMED 1990, HILLER 1994):

- Jurassic sandstones and carbonates in the northern part of the Punjab Monocline, where some gas reserves have been found at Panjpir (30° 40' 49"N; 71° 57' 29"E) and Nandpur (30° 31' 45"N; 71° 55' 38"E);
- Dungan Formation Limestone of Paleocene age with gas reserves in the Loti (28° 56' 08"N; 69° 04' 01"E) and Pirkoh (29° 07' 45"N; 69° 08' 07"E) Fields;

- Lower Eocene Laki Formation Limestones (contemporaneous with the Sakesar Formation Limestones in the Kohat-Potwar Foredeep), where very large gas accumulations have been found in the Sui Field, and discoveries were made at Uch and Zin.

7.14 Central Lower Indus Basin and Kirthar Foredeep

This central part of the Lower Indus Basin is separated from the Sulaiman Foredeep by the northwest trending Mari-Kandhkot High. To the east, the Neogene foredeep sediments thin out over the north trending Jacobabad High. Southwards, the Lower Indus Basin continues offshore (Fig. 7.6). It is terminated in the west by longitudinal suture zones (Figs. 2.4, 7.1).

Structurally, this part of the Indus Basin is similar to the northern Lower Indus Basin and Sulaiman Foredeep. Well data and seismic control indicate normal faulting of the Mesozoic section, a fault set which was most probably rooted in the basement. The Mari-Kandhkot and Jacobabad Highs might have originated with such faulting, but since the Cretaceous, they formed swells which continued to influence the depositional pattern through the Palaeogene and Neogene. Westwards tilting of the entire region after collision of the Indo-Pakistan Plate with the Afghan Blocks, resulted in the development of a large monocline, the southern continuation of the Punjab Monocline, offset to the west by the Sibi Re-entrant (Fig. 7.5). The sedimentary basin axis trends south; so do the structures which follow the oblique collision (Fig. 7.6).

Stratigraphy and **palaeogeography** are discussed in Chapters 3 and 6 (Figs. 6.9, 6.11).

The **source rock** potential (EICKHOFF & ALAM 1991, RAZA 1991) of the Mesozoic sequences appears to be limited with total organic carbon contents (TOC) generally less than 1 %, and the genetic potential (gp) mostly below 1 kg/t. The Dunghan/Ranikot Formations of Paleocene age show higher values with modest potential. Within the Eocene Ghazij Group, oil shales are developed, which have an excellent source potential in the Sibi area (gp: 83 kg/t) and in the Dadu area (gp: 30 kg/t). Coal beds and coaly matter add to the hydrocarbon source possibilities. As in the Sulaiman region to the north, the Eocene Kirthar Formation in the Kirthar region contains oil shales with good to excellent oil and/or gas potential (TOC up to 7.9 %, gp up to 47.9 kg/t).

Variations in source rock **maturity** are shown on Fig. 7.7 (isothermal gradients) and Fig. 7.8 (vitrinite reflectance values versus Formations). All described source rocks had or have reached oil- or gas-generating maturity during the palaeogeothermal and burial history.

The more important known and potential **reservoir rocks** are:

- Lower Goru Formation sandstones (Lower Cretaceous) and the coeval Lumshiwal Formation sandstone,
- Pab Formation sandstone (Upper Cretaceous),
- Habib Rahi and Pirkoh Limestones of the Kirthar Formation (Eocene),
- Nari Formation sandstones (Oligocene),
- Siwalik Group sandstones (Neogene).

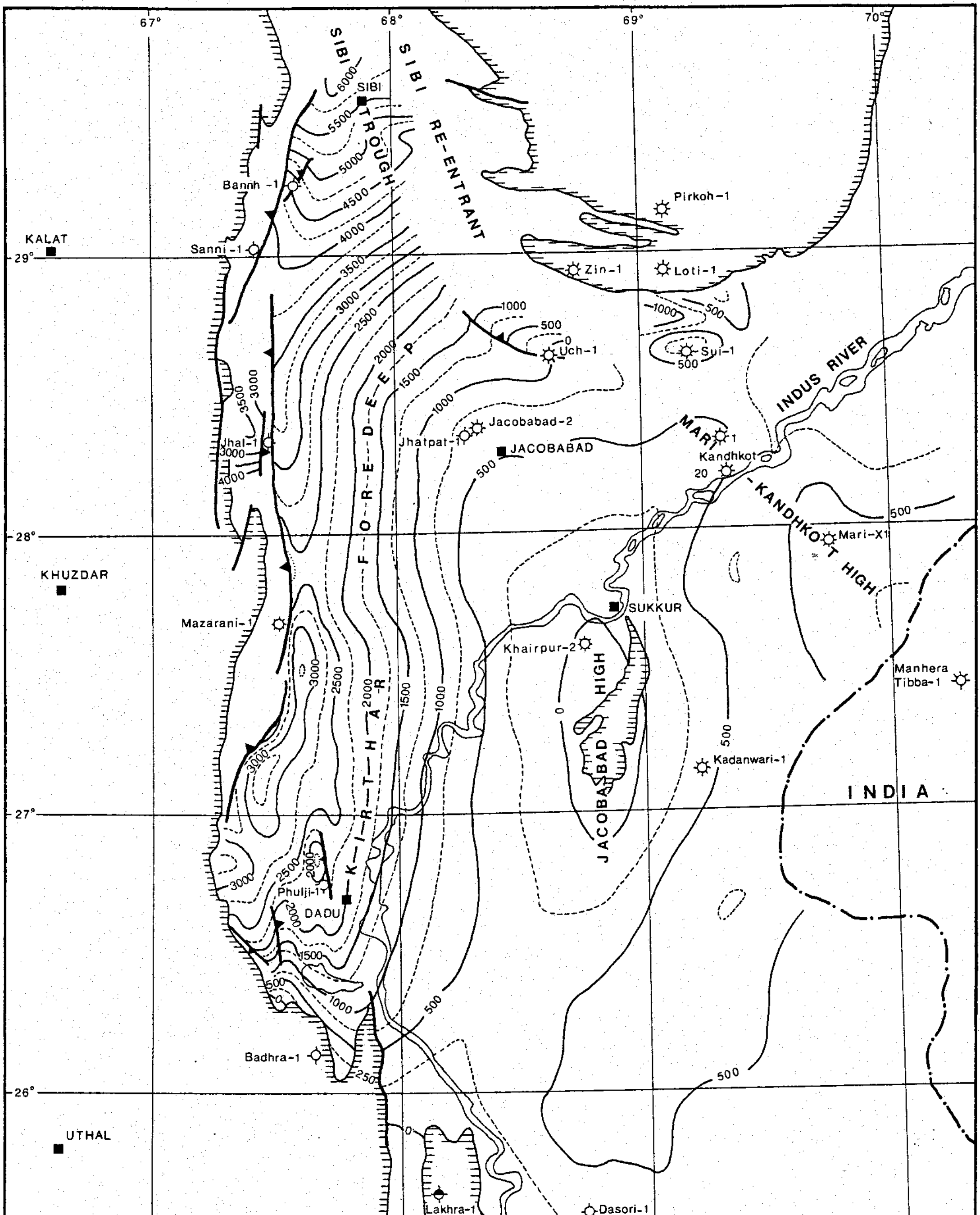


Fig. 7.6. Depth contour map of base Miocene of the central and southern Lower Indus Basin (after EICKHOFF & ALAM 1991).

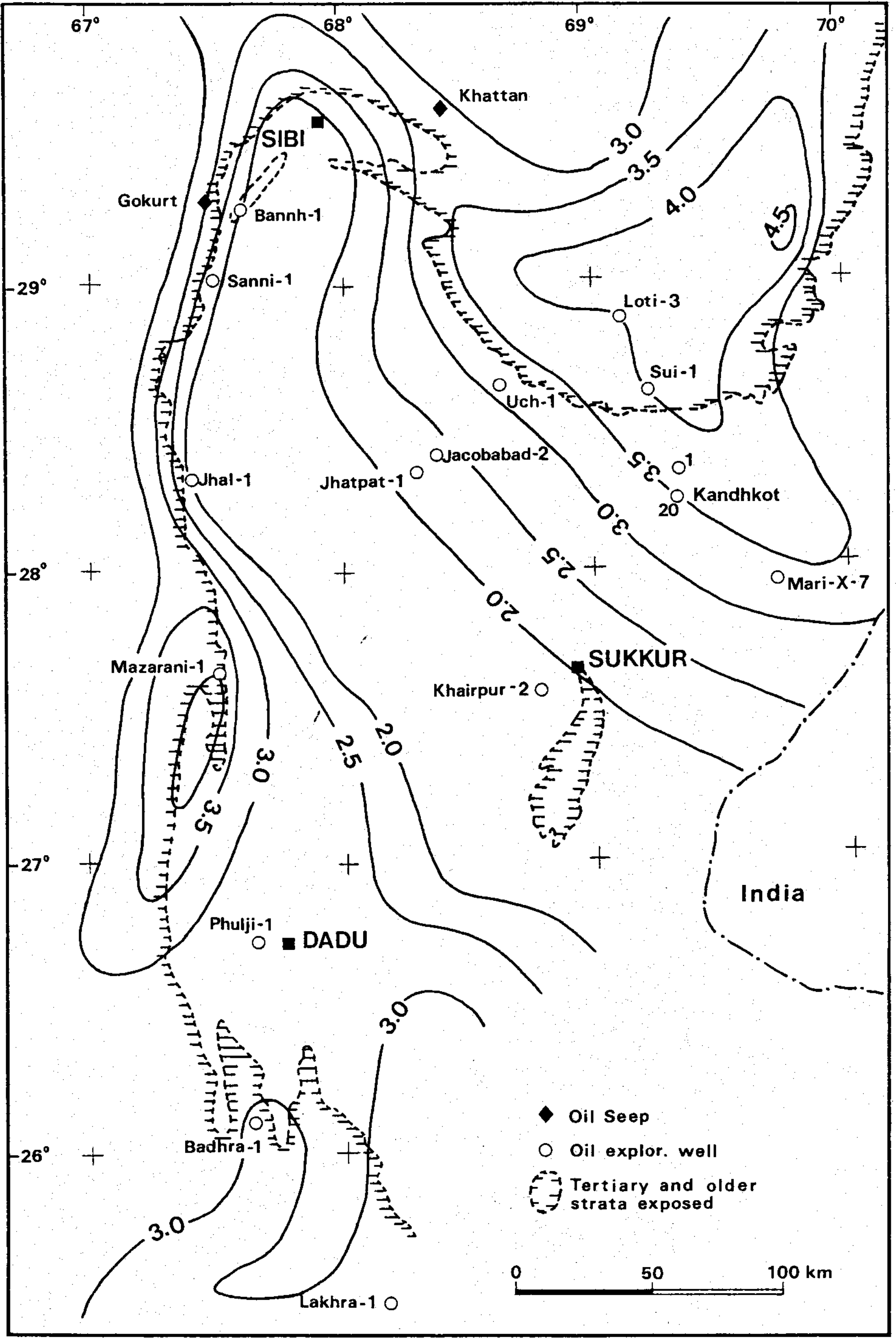


Fig. 7.7. Isothermal gradient map of the central and southern Lower Indus Basin (after EICKHOFF & ALAM 1991, fig. 39).

Cap rocks with good qualities and wide lateral extent include shales and marls in the Lower Cretaceous Goru Formation above the Lower Goru Formation sandstones, shales in the Paleocene Upper Ranikot Formation (= Lakhra Formation), shales equivalent to the Habib Rahi and Pirkoh calcareous facies, shales in the Eocene Ghazij Group (Ghazij Shale), and shale intercalations within the Neogene Siwalik Group.

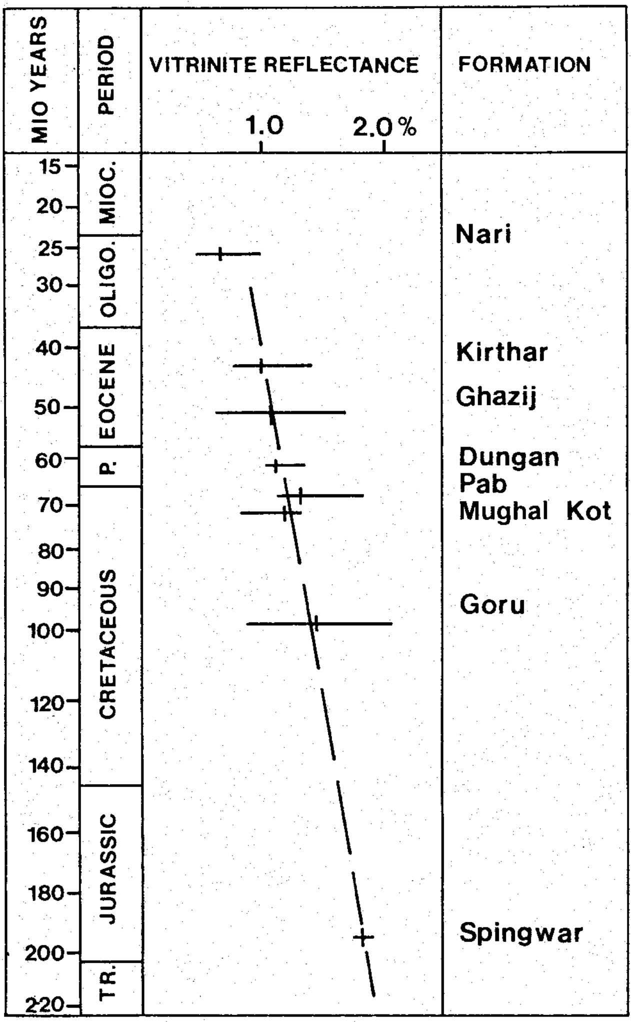


Fig. 7.8. Maturity versus Formations of surface rock samples from Kirthar Range area (after EICKHOFF & ALAM 1991, fig. 27).

Structural traps in the central Lower Indus Basin and in the Kirthar Foredeep are in general comparable with those in the northern Lower Indus Basin, including
- intensely thrusted, faulted and folded structures along the eastern margin of the Kirthar Range,
- elongated and narrow anticlines partly associated with thrusts and faults in the Kirthar Foredeep,
- broader anticlines and tilted horst blocks, in the area of the monocline to the east of the Foredeep (Fig. 7.1).

Possible **hydrocarbon prospects** (for details: DOLAN et al. 1987, EICKHOFF & ALAM 1991, HILLER 1994) exist along the eastern margin of the Kirthar Range, especially in Eocene limestone reservoirs, including possibilities below extensive overthrusts. In the Kirthar Foredeep and the area of the Monocline, onlapping Upper Cretaceous and Paleocene sequences can be considered as prospective; so are the areas of the Mari-Kandhkot and Jacobabad Highs in potential reservoir rocks below unconformities.

7.15 Southern Lower Indus Basin and offshore area

This region comprises the area south of the Jacobabad High (Fig. 7.6) (approximately south of 27°N), west of the Indian Shield, and east of the Bela-Waziristan Ophiolite Zone. Offshore to the south, the region is bordered in the west by the Owen-Murray ridges (Figs. 2.5, 5.1, 7.1).

As in the central Lower Indus Basin, the **structural framework** is a result of the rifting during Triassic, oblique collision of the Indo-Pakistan Plate with the Afghan Blocks during the Late Cretaceous and Palaeogene, and by post-collisional deformation during Neogene and Quaternary times. Again, the major structural trends and the basin axis trend generally south, but with a "bulge" to the east (north of Karachi) where structures trend southeasterly. Depth contours on the base of the Tertiary show a rise from about 6,000 m bel.s.l. in the west to about 1,000 m bel.s.l. approaching the Indian Shield in the east, with the Karachi trough deepening from 1,000 m bel.s.l. to more

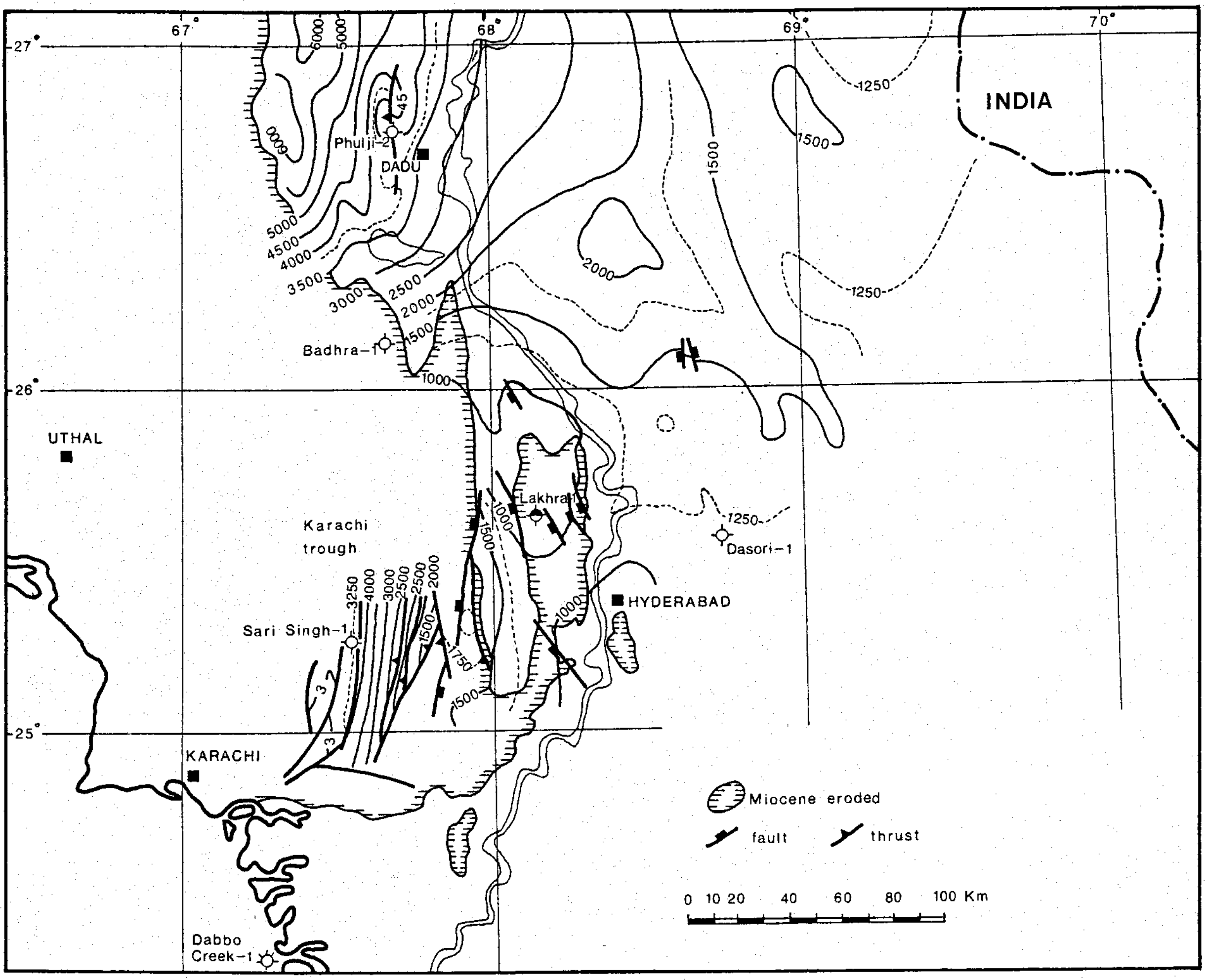


Fig. 7.9. Depth contour map of base Tertiary of the western part of the southern Lower Indus Basin (after EICKHOFF & ALAM 1991, fig. 27).

than 3,250 m bel.s.l. (Fig. 7.9). In the offshore area east of the Murray Ridge, a deltaic platform is developed which, on a NNE-north striking hinge line, leads to the west into a deep basin of Miocene sediments (Fig. 7.10).

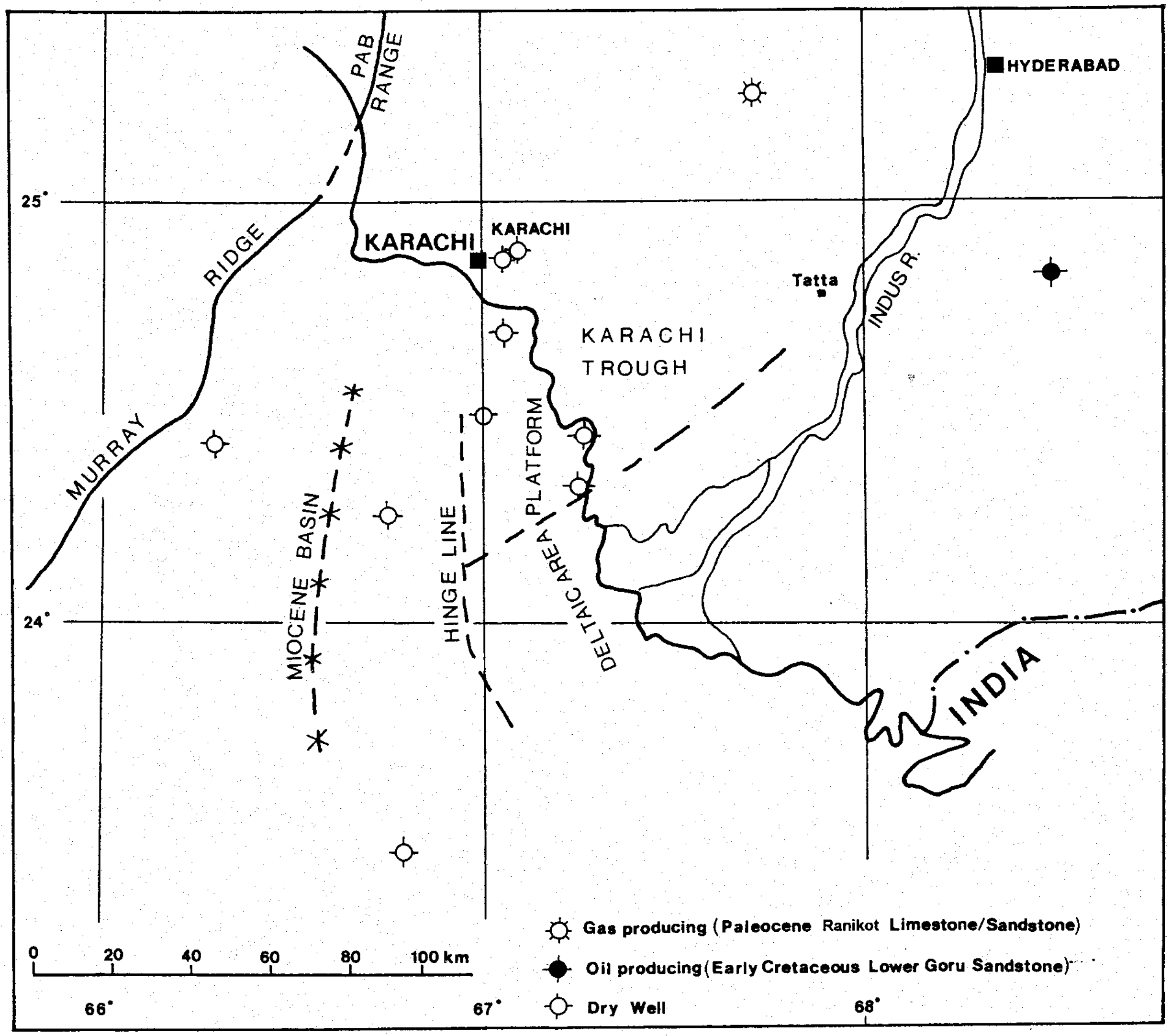


Fig. 7.10. Structural sketch map of offshore southern Lower Indus Basin (simplified after QUADRI 1982, fig.1).

Stratigraphy and palaeogeographic development are discussed in Chapters 3.3 and 3.4, and in Chapters 6.41 and 6.42 (Figs. 6.8, 6.9, 6.11). The oldest rocks drilled in the offshore area belong to sequences of the Lower Cretaceous Sembar and Goru Formations, and of the Upper Cretaceous Parh, Mughal Kot and Pab Formations. Above these were encountered the Ranikot (Paleocene), Ghazij, Laki, Kirthar (Eocene), Nari (Oligocene) and Gaj (Miocene) Formations, covered by very thick post-Miocene deposits in the Indus Delta fan area (QUADRI & SHUAIB 1987).

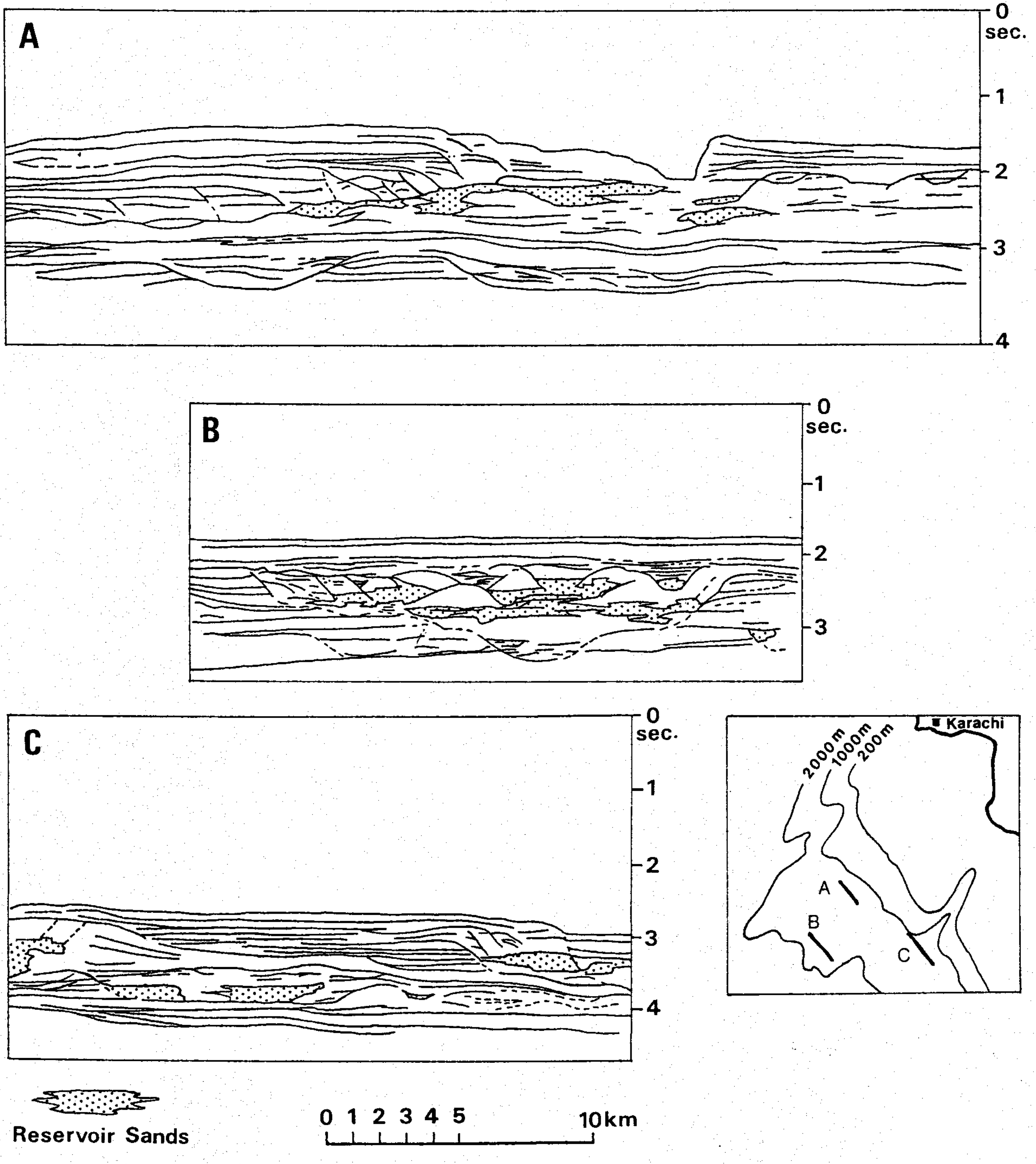


Fig. 7.11. Indus fan channel reservoir sands (after McHargue & Webb 1986 in Dolan et al. 1987, fig. 33).

Potential **source rocks** (Raza & Alam 1983, Dolan et al. 1987, Alam 1989) have been suggested within the Middle Jurassic Chiltan Formation. Good quality source rocks are in the Lower Cretaceous Sembar and Goru Formations, whereas no significant occurrences have been reported from the Upper Cretaceous sequences. Eocene source rocks are developed within the Khadro and Dunghan Formations as interbedded shales and lateral basinal shales. Their time equivalents are of good source quality in the

Cambay Basin, India (BHANDARI & CHOWDHARY 1975, GAMBHIR 1976). The Lower Eocene Ghazij Group shales and the Middle/Upper Eocene sequences (e.g. Kirthar Formation) might contain source rocks as they do in the central Lower Indus Basin. Within the offshore Miocene/Pliocene sequence (e.g. Gaj Formation), potential reservoir rocks are developed as well (SHUAIB 1982, MCHARGUE & WEBB 1986; Fig. 7.11).

In extensive parts of the onshore area, the Jurassic, Cretaceous and Palaeogene source rocks are at **maturity** levels which have generated oil, condensate or gas. This applies also for Neogene sources in the offshore area.

The more important potential **reservoir rocks** in the northern, central and the southern Lower Indus Basin, and in the offshore area are listed in Table 7.1.

Table 7.1. Reservoir rocks in the Lower Indus Basin and in the Indus offshore area (compiled from SHUAIB 1982, QUADRI & SHUAIB 1987, DOLAN et al. 1987).

Jurassic	Shinawari Fm. sandst.	porosity up to 35 %	gas at Nandpur
	Samana Suk Fm. sandy limest.	5 % – 25 %	gas at Nandpur
	presumably Jurassic sandst.		water in Nabisar-1 well
	Chiltan Fm. oolithic limest.		gas in Nandpur/Panjpir area
Cretaceous	Goru and Sembar Fm. sandst.	5 % – 40 %	oil, gas and condensate in Khaskeli area
	Lumshiwal and Chichali sandst.	up to 35 %	gas in Nandpur/Panjpir area
	Mughal Kot Fm. carbonates	poor	gas in Jandran-1 well
	Pab Fm. sandst.	up to 20 %	
Tertiary	Ranikot Group sandst. and limest., Dungan Fm. limest.	10 % – 15 %	gas in Kothar, Hundi and Sari Sing fields; Shahdadpur wells
	Laki Fm. limest.	5 % – 32 %	gas and condensate in Mazarani-1 well
	Kirthar Fm. limest.		gas in Mari field; Karachi wells; Korangi Creek-1 well
	Nari Fm. sandst.		gas in Karachi-1 well
	Gaj Fm. sandst.		coastal and offshore areas, canyon channels
Pliocene/ Pleistocene	channel sands		delta and fan deposits

Cap rocks comprise mainly shales in the upper part of the Gora Formation (Lower Cretaceous), shales and chalky limestones in the upper part of the Cretaceous Parh Formation, and interbedded shales in the Kirthar (Eocene), and Nari (Oligocene) Formations.

The post-Cretaceous depositional pattern is more complex as compared with earlier periods of time, showing rapid facies changes not only of reservoir but also of sealing rocks, particularly from Miocene time onwards.

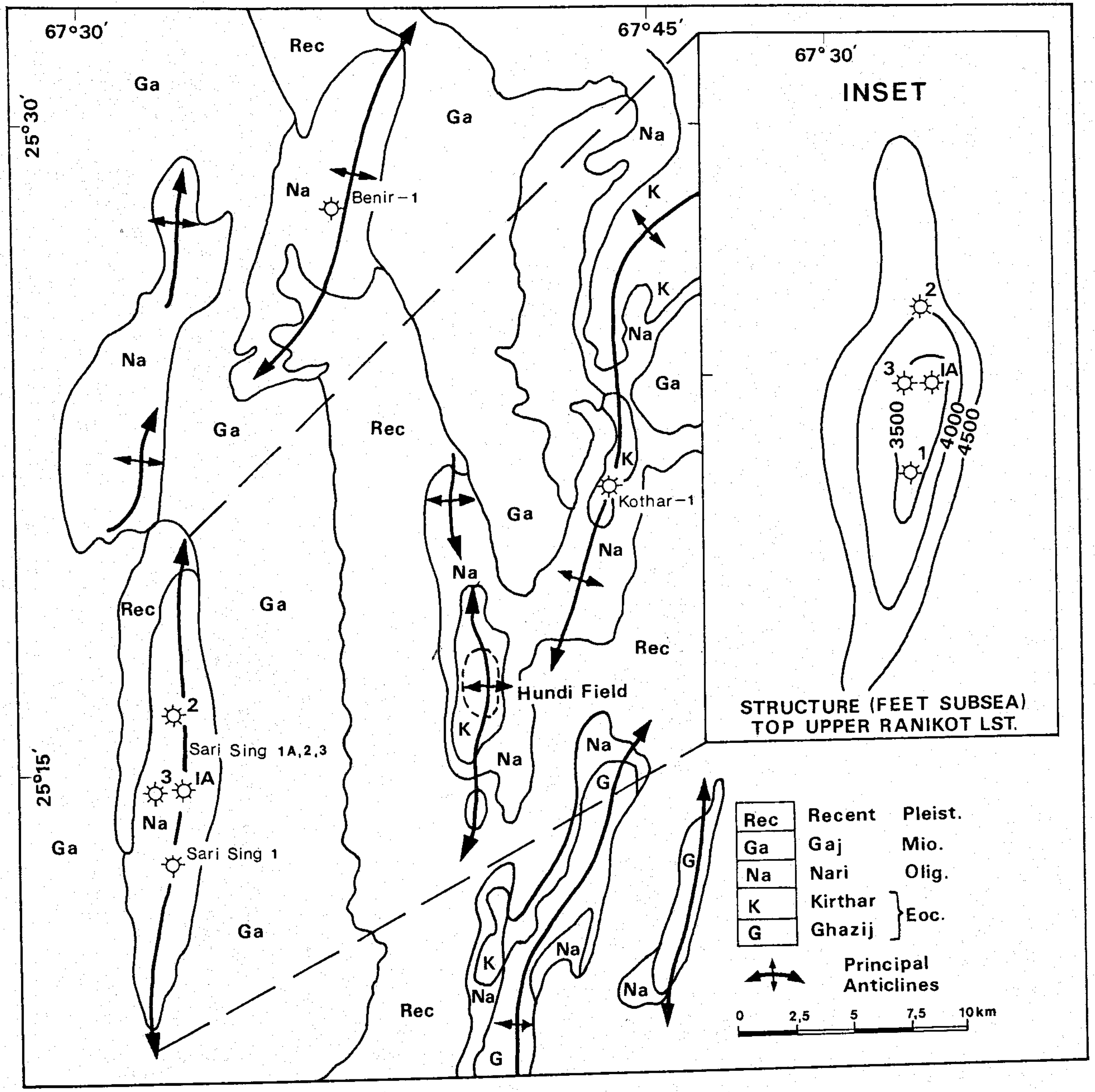


Fig. 7.12. Structural map of Sari Sing-Benir-Hundi area in the Lower Indus Basin (after DOLAN et al. 1987).

Structural traps trend mainly north; they comprise faulted or thrusted anticlines along the southern continuation of the Kirthar Foredeep, and are commonly asymmetric, with steeper flanks to the east (e.g. Sari Sing (25° 13' 15"N; 67° 32' 20"E, gas); Hundi (25° 12' 00"N; 67° 42' 00"E, gas); Fig. 7.12). In approaching the Indian Shield to the east, the anticlines are generally broader and less affected by faulting.

Stratigraphic traps appear in combination with faulting and facies changes as "roll-over" structures, typical of a major deltaic depositional environment (Khaskeli area, oil). The latter is developed offshore as well (MCHARGUE & WEBB 1986; Fig. 7.11).

Further stratigraphic traps may exist in onlapping Cretaceous and Tertiary sequences and truncated source rocks below unconformities.

The **hydrocarbon prospectivity** has been variously described (SHUAIB 1982, McHARGUE & WEBB 1986, QUADRI & SHUAIB 1987, DOLAN et al.1987) as:

- Jurassic sequences; clastic rich, overlain by Lower Cretaceous source rocks, and block-faulted,
- Lower Cretaceous sandstones (cluster of oilfields in the Badin area: Khaskeli Field (24° 47' 41"N; 68° 34' 15"E)),
- Paleocene sequences; probable belt of marginal marine sandstones along the southwestern flank of the Jacobabad High, may be transgressive belt of carbonates; truncated reservoir rocks below unconformities,
- Eocene sequences with comparable possibilities,
- Oligocene and post-Oligocene sequences in the Indus delta and fan area with reservoir quality sands and probably reefal limestones along the hinge line, and at the upper flank of the Miocene basin west of it (Figs. 7.7, 7.8).

7.16 Baluchistan region and offshore area

This region, as defined here, lies west of the suture and fault zones which separate the Indo-Pakistan Plate from the Afghan Blocks (Fig. 2.5). Offshore, it comprises the area west of the Murray Ridge (Fig. 7.10). The geological history of the region is very different from that of the region east of the sutures/faults (see Chapter 6.42). The deposition of the pre-Upper Cretaceous sedimentary sequences took place geographically remote from those deposited in the Indus Basin until they came in juxtaposition during the Late Cretaceous and Early Tertiary phase of collision. According to a recent conceptual model by RAZA et al. (1991), the "Baluchistan Basin" has been interpreted as an extra-continental subduction basin which has been subjected to plate convergence to such an extent that the arc has been destroyed by subduction and transform movements, reducing it to a non-arc basin.

The **structural setting** is oriented west-east-northeast and complicated because of the oblique collision between the Indo-Pakistan and Eurasian Plates, the northward-directed movement and collision of the Arabian Plate, and the rotation of individual tectonic units (see Chapters 2.21 through 2.23, 5.23, 5.24, 6.33; Figs. 2.1, 2.2, 5.1). The Makran area comprises an accretionary prism with turbidities succeeded by bathyal to shoreline slope and shelf deposits that have been deformed into southward overturned folds (HARMS et al. 1982, RAZA & ALAM 1983).

Stratigraphy is discussed in Chapters 3.3 and 3.4. A schematic cross-section from the Chagai Hills to the Arabian Gulf (Fig. 2.8) shows that sedimentary basins developed during Paleocene through Miocene sequences which mainly consist of flysch-type sediments. Such flysch basins or troughs are the Makran-Khojak-Pishin (Katawaz in Afghanistan) troughs, and the Dalbandin trough (Figs. 2.13, 7.1). The great thicknesses of the flysch sediments (more than 5 km) are caused by slumping of unconsolidated rocks and by repetitions of sequences as a result of tectonic movements.

Except for the Makran coastal area, little is known about **source and reservoir rocks.** In the area of the Volcanic Arc (see Chapter 5.24), the Paleocene Rakshani Formation is dominantly sandy with interbedded shales and limestones. In the Ras Koh area, the Lower and Middle Eocene is represented by shallow water limestones, the Kharan Formation. It is reefoid in part, highly fossiliferous and with a distinctive fetid odour. In the Makran area, Eocene sequences comprise a similar limestone unit, also with a bituminous odour. These interbedded shales and limestones were considered to be of prime interest by RAZA & ALAM (1983) and ALAM (1989). The Eocene/Oligocene/Lower Miocene flysch-type sediments (Khojak Formation, Middle Miocene Parkini Formation mudstone; TOC generally above 0.5 %) above the limestones comprise thick shales which might also serve as sealing **cap rocks**. The Wakai Limestone in the western Makran area (probably a member of the lower part of the Khojak Formation) may have **reservoir** characteristics. In the upper parts of the Khojak Formation, mixed clastics are developed also with potential reservoir qualities. The Hinglaj Group (Upper Oligocene/Miocene/Pliocene) comprises turbiditic flysch-type sequences deposited in deep water. They coarsen upwards and prograde south towards the present-day Makran coast (DOLAN et al. 1987) with Middle Miocene sandstone of good reservoir characteristics (HARMS et al. 1982).

In the Makran coastal area, subsurface samples range from 0.22 % to 0.96 % total organic carbon (TOC), thus implying poor potential **source rocks** in post-Middle Miocene sequences. Because there is a very large volume of mudstone deposited in slope and outer shelf environments, a large volume of TOC might have reached maturity levels (HARMS et al. 1982). Numerous mud volcanoes appear in the Makran area, usually along faults or fold lineaments. They are associated with gas seeping, mainly methane (DIN 1965). The source of the gas is not clear.

Only scant data are available on **maturity** suggesting that the geothermal gradient appears to be relatively low in the Makran area (1.5 °C to 2.5 °C/100 m; KHAN & RAZA 1986). Traces of heavier hydrocarbons and isotopic compositions of the mud volcanoe gas seeps indicate generation from thermally mature source rocks (HARMS et al. 1982).

Attractive **structures** were defined in the Makran coast and offshore area which comprise long, narrow, asymmetric to overturned isoclinal anticlines, separated by broader synclines. They trend west to east with anticlinal axes commonly nearly parallel for large distances. Offshore seismic data imply extensive detachment at depth (HARMS et al. 1982). Comparable structural trends are observed further inland to the north (Fig. 2.8), with northwards-increasing deformation, including reverse faults which brought older sequences in juxtaposition with younger ones.

Any assessment of possible **hydrocarbon prospects** would be speculative except for the coastal and offshore area. Also in this area, source rock quality, level of maturity and reservoir rock properties are far from being fully evaluated with only five exploratory wells in an area of about 40,000 km^2. Very high pressures were encountered while drilling which prevented the evaluation of potential Middle Miocene reservoir targets. HARMS et al. (1982) considered the southern flank of the Pasni Anticlinorium offshore Pasni as attractive for additional exploration.

7.2 Bituminous rocks

(Hans Porth)

The term "bituminous rocks" is here used in the sense of the technical term "oil shales" as being applied for shale, siltstone, marlstone or limestone containing a considerable

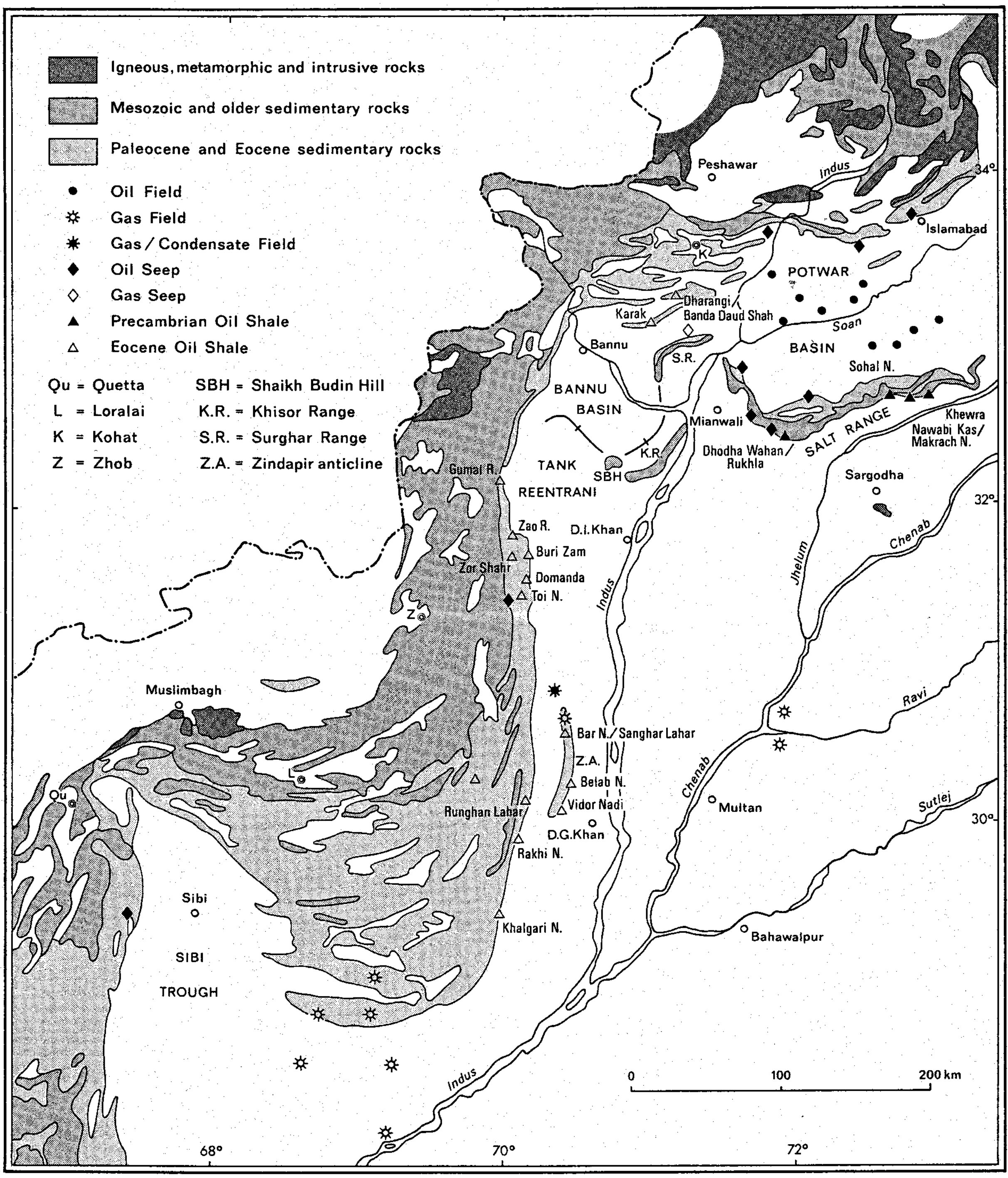


Fig. 7.13. Oil shale localities in Salt Range, Kohat area and Sulaiman Range (geology simplified after Bakr & Jackson 1964).

primary percentage of sapropelic and/or bituminous matter. Rocks containing migrated hydrocarbons, e.g. oil-impregnated sandstones, siltstones or limestones, however, are not discussed in this Chapter. Exploitable oil shales should have at least 6 % to 7 % by weight organic matter and an oil yield of 10 gallons per ton of rock (MASTERS et al. 1987). Oil shales are widely distributed in Pakistan (Fig. 7.13). High-grade oil shales are

Table 7.2. Analytical data for selected samples of oil shales from Salt Range, Kohat area and Sulaiman Range (after PORTH et al. 1987).

	Sample No.	TOC	EOM	gP	Oil yield		GCV
Eastern Salt Range					a)	b)	
Salt Range Formation							
Khewra	SaR-70	36	45,763	278	21	225	19,420
Nawabi Kas	SaR-142	31	78,922	250	20	214	
Makrach Nala	SaR-202	31	39,565	219	16	180	
Sohal Nala	SaR-211	23	43,389	138	8.7	95	
Western Salt Range							
Salt Range Formation							
Rukhla	SaR-229	8.2	11,613	61			
Dhodha Wahan	SaR-264	7.2	10,280	43			
Kohat area							
Jatta Gypsum							
Dharangi	Ko-76	25	39,888	151	13	148	
Banda Daud Shah	Ko-137a	24	19,619	209	13	146	
Sulaiman Range							
Pirkoh Limestone							
Bar Nala	SmR-411	4.6	2,450	26	2.3		
Sanghar Lahar	SmR-416	4.0		22			
Rahki Nala	SmR-427	4.0		25			
Khalgari Nala	SmR-444	4.9	2,168	23			
Gumal River	SmR-459	3.8	1,276	22			
Habib Rahi Limestone							
Buri Zam	SmR-203	4.7	5,241	7	3.6	38	
Zor Shahr	SmR-204	3.6	4,436	27	3.3	36	
Belab Nala	SmR-253	9.4	11,256	66	5.1	53	
Sanghar Lahar	SmR-415	11.0	9,516	66	4.5	49	5,130
Vidor Nadi	SmR-432	6.4		50	4.0	43	2,770
Runghan Lahar	SmR-439	10.1		69	5.0	53	4,780
Khalgari Nala	SmR-440	8.1	7,003	68	6.5	70	4,610

TOC	total organic carbon (%)
EOM	extractable organic matter (ppm of rock)
gP	genetic potential (kg hydrocarbons per ton of rock)
Oil yield	Fischer Assay a) % of rock weight, b) liters per ton of rock
GCV	gross calorific value (kJ per kg of rock)

present in the Precambrian sequences of the Salt Range, and in the Eocene of Kohat. They can be rated among the richest oil shales in the world.

In the eastern Salt Range, high-grade oil shales are present in the Salt Range formation, as thin intercalations in the gypsum horizon forming the top of the Formation. A maximum thickness of 1 m to 2 m was observed. In places, the total organic carbon content (TOC) exceeds 30 % and the oil yield is more than 200 l/t (Table 7.2). The oil shales (black organic shales) are locally mined as "coal". In the western Salt Range, the middle part of the Salt Range Formation contains a sequence of sandstone, siltstone, dolomite and gypsum with intercalated thin, laminated oil shale layers (maximum thickness 0.6 m, maximum TOC 8 %).

In southern Kohat, the top of the Eocene saline series is formed by the Jatta Gypsum which contains layers of high-grade oil shales locally more than 3 m thick (maximum TOC 27 %, oil yield up to 20 %). RASHID et al. (1965) reported a maximum thickness of 6 m from Banda Khanda (Fig. 7.13). The oil shales (black or dark-brown, in part distinctly laminated organic shales) are locally being exploited as burning material for lime kilns.

In the Sulaiman Range, low-grade oil shales are widely distributed in the Middle Eocene Kirthar Formation. They could be traced over more than 300 km from South Waziristan in the north to Jampur in the south (PORTH & RAZA 1990 b). Along the eastern slope of the Sulaiman Range, oil shales are developed in two different stratigraphic levels of the Kirthar Formation, an upper level ("Pirkoh Limestone") and a lower level ("Habib Rahi Limestone"), separated by a thick sequence of shales and claystones ("Sirki Shale").

The Pirkoh Limestone is an alternation of yellowish-grey limestones and dark-brown to black, bituminous, commonly laminated, white-weathering marlstones which contain fish scales. The thickness of this sequence, which is underlain by a *Discocyclina* limestone bed, ranges from 5 m to 10 m. The maximum observed TOC of the oil shale layers is 4 % to 5 %.

The Habib Rahi Limestone, which characteristically begins with a compact *Assilina* limestone bed at the base, is much thicker than the Pirkoh Limestone. The lithology is very similar to that of the Pirkoh Limestone. Fish remains, including whole, well-preserved fishes, are likewise abundant. The intercalated oil shales are of a distinctly better quality than those of Pirkoh Limestone (maximum TOC 11 %, oil yield up to 6.5 %). The oil-shale sequence of the Habib Rahi Limestone is best developed in Sanghar Lahar, in the northern part of the Zindapir Anticline, west of Taunsa:

60 m to 80 m	Dark-grey to black shales with interbeds of dark brownish-grey to brownish-black, silty, bituminous shales and platy, bituminous marlstones; some marly limestone intercalations.
30 m	Alternating thin-bedded, yellowish-grey, marly limestones with black chert layers and lenses, and brownish-grey, platy marlstones. Common interbeds of dark-brown to brownish-black, light bluish-grey weathering, partly laminated, calcareous, bituminous shales and marlstones. Abundant fish remains (scales, teeth, fins, partly complete skeletons).
2 m	Massive limestone bed with abundant *Assilina* ssp.

In other parts of the Zindapir Anticline and in the central Sulaiman Range, the thickness of the Habib Rahi Limestone including the associated oil shales reaches 50 m to 60 m.

Satellite-image interpretation indicated that the oil shales found in the Sulaiman Range extend southward into the "Southern Sulaiman Lobe" (Pirkoh area) (verbal communication BANNERT 1986). Farther to the south, however, they are thinning rapidly. EICKHOFF & ALAM (1990) reported the presence of thin oil-shale layers within the Kirthar Formation: 0.3 m + 0.6 m in the Sukleji River and 1.3 m in the Gaj River section.

7.3 Coal

(ALI H. KAZMI)

Coal has been mined for several decades in the territory that comprises Pakistan today. Despite the fact that coal produced in the Punjab and Baluchistan has been largely lignitic to sub-bituminous, of high volatile and high sulphur content and of a lower quality than the Indian anthracitic coal, before the political division of the subcontinent its market extended as far east as Bihar (India). After the discovery of natural gas in Bugti area (Baluchistan), Pakistani cement factories switched over to natural gas as fuel instead

Table 7.3. Identified coal reserves and hypothetical coal resources in Pakistan coal fields (mio. t); after KAZMI & ABBAS (1991).

coal field	average mineable thickness (m)	identified				hypothetical	grand total
		proved	indicated	inferred	total		
Punjab							
Makarwal	0.75	5	8	9	22	–	22
Salt Range	1.5	43	13	–	56	178	234
Baluchistan							
Sor Range	1.75	15	–	19	34	–	34
Pir Ismail Ziarat	0.5	1.5	1.5	8	11	–	11
Mach-Abegum	0.75	9	–	14	23	–	23
Khost-Sharigh Harnai	0.75	13	–	63	76	–	76
Duki	0.5	14	11	25	50	–	50
Sindh							
Lakhra	1.5	224	629	739	1,592	28	1,640
Sonda	–	188	1,388	5,724	7,300	–	7,300
Meting	0.5	10	43	108	161	–	161
Badin	–	–	–	–	–	9,000	9,000
Thar Desert	–	–	–	–	–	1,200	1,200
Total		542.5	2,093.5	6,709	9,345	10,406	19,751

of the indigenous coal. The Pakistan Railways also changed over from steam powered locomotives to diesel powered engines, thus eliminating another possible market for Pakistani coal. It has been ever since used mainly in brick industry and its role in the energy scenario has decreased from about 60 % in the late forties to about 5 % at present (AHMED et al. 1986). Despite this restricted market at present, Pakistan's coal

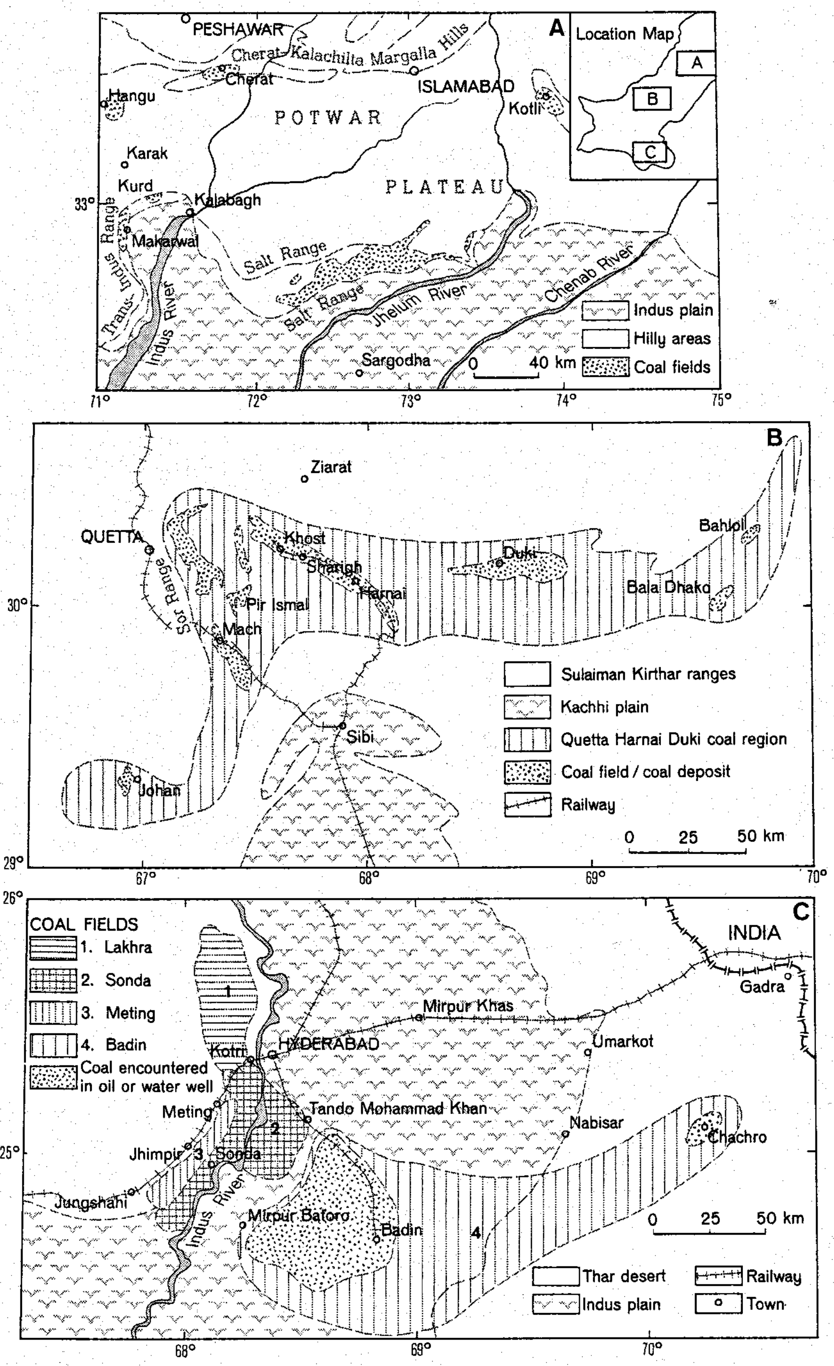


Fig. 7.14. Sketch maps of coal-bearing regions and coal fields in Pakistan: A: Kohat-Potwar coal region; B: Quetta-Harnai-Duki region; C: southern Sindh coal region.

resources are likely to be of considerably greater importance in the future. A review of the country’s energy resources and future requirements show that by the year 2000, the present major sources of energy (i.e. gas, oil and hydroelectric), will not meet the anticipated demand (KHAN et al. 1990). It is now obvious that Pakistan’s coal resources will play a major role for a long time to come. Initially estimated at about 500 mio. t (KHAN 1950), recent studies place Pakistan’s coal resource base at over 9 billion t. (Table 7.3; KAZMI & ABBAS 1991).

Coals are mainly in Paleocene and Eocene rocks, though coal is also present at one locality in Late Permian rocks of the Salt Range. The known coal bearing rocks are in three geologically and/or geographically distinct regions, each of which includes two or more smaller entities that might be called areas or fields. From north to south these are (Fig. 7.14):

- The Kohat-Potwar coal region which lies in the Kohat-Potwar stratigraphic province of the Indus Basin.
- The Quetta-Harnai-Duki coal region which covers northeast Baluchistan and forms a part of the Sulaiman stratigraphic province of the Indus Basin.
- The Southern Sindh coal region which comprises the southern part of the Kirthar stratigraphic province of the Indus Basin.

7.31 Kohat – Potwar region

Structurally this is the most complex region of the Indus Basin (see Chapter 7.1). It includes a thrust belt encompassing the hill ranges of Kohat, southern Hazara, Margalla, Kalachitta and Attock-Cherat, the fold belt of the Kohat-Potwar Plateau, and the Salt Range. The Salt Range forms the southern limit of the region.

Coal is present in rocks of Permian age only at Burikhel (32° 41’N; 71° 38’E) in the Salt Range. It is detrital in a coarse pebbly sandstone bed. The average thickness is about 62 cm. The coal contains sandstone partings. Reserves are only about 360,000 t (SHAH 1980).

Elsewhere in the Kohat-Potwar region coal is in rocks of Paleocene age. In ascending order, the Paleocene sequence consists of the Hangu Formation, the Lockhart Limestone and the Patala Formation (see Chapter 3.41; Fig 7.15). In the Makarwal (32° 52”N; 71° 72’E), Karak (33° 06’N; 71° 04’E) and Hangu (33° 32’N; 71° 03’E) areas, the coal is in the basal part of the Hangu Formation (Fig. 7.15). According to WARWICH & HUSSAIN (1990) the coal was deposited in coastal swamps.

The Hangu Formation is conformably overlain by the Lockhart Limestone which contains intercalations of marl and shale. It is about 30 m to 260 m thick and is conformable and transitional with the overlying Patala Formation (Fig. 7.15). Coal beds are present in the lower part of the Patala Formation in the Kotli area and the central and eastern Salt Range. According to WARWICK & SHAKOOR (1988), the Patala coal has been deposited in back-barrier and near-marine environments. The upper contact of the Patala Formation is conformable and transitional with the overlying Eocene Nammal Formation (CHEEMA et al. 1977).

In the Kohat-Potwar region there are two main coal fields, one located in the Surghar Range, known as the Makarwal coal field and the other located in the central and eastern Salt Range (Fig. 7.14). Smaller deposits occur near Hangu, Cherat (33° 51'N; 71° 53'E) and Kotli (33° 31'N; 73° 54'E).

Table 7.4. Chemical range analyses of coal from various coal fields (after AHMED et al. 1986).

coal field	*proximate analysis (%)*					
	moisture	volatile matter	fixed carbon	ash	heating value (in kcal/kg)	rank
Makarwal (Surghar Range)	2.8- 6.0	31.5-48.1	34.9-44.9	6.4-30.8	5,200-6,780	high-volatile bit. C to bit. B
Salt Range	3.2-10.8	21.5-38.8	25.7-44.8	12.3-44.2	3,760-6,170	high-volatile bit. C
Sor Range-Deghari	5.1-21.2	31.0-43.1	36.0-43.0	2.7-14.3	4,830-6,060	sub-bit. B to sub-bit. A
Pir Ismail Ziarat	5.2-10.0	27.0-41.5	23.8-37.2	13.3-34.2	5,353-5,939	high- volatile bituminous C
Mach	7.1-12.0	34.5-39.5	32.4-41.5	9.6-20.3	5,100-5,730	sub-bit. C to sub-bit. B
Khost-Sharig-Harnai	1.7-11.4	29.7-45.7	25.5-45.2	9.3-38.0	4,420-7,000	high volatile bit. B to bit. A
Duki	4.8- 9.2	36.5-53.0	14.3-38.9	2.7-22.3	4,610-6,380	sub-bit. C to sub-bit. A
Bahlol Bala Dhaka	7.9-11.8	34.9-38.4	31.0-52.1	1.6-29.2	n. d.	not determined
Lakhra	13.5-39.4	26.3-42.5	20.7-39.2	7.4-25.0	2,570-4,200	lignite A to sub-bit. C
Sonda	9.0-39.5	20.0-44.2	15.0-58.8	5.0-39.2	3,600-5,700	lignite A to sub-bit. B
Meting-Jhimpir	26.6-36.6	25.2-34.0	24.1-32.2	8.2-16.8	3,740-4,260	lignite A to sub-bit. C

coal field	hydrogen	carbon	nitrogen	oxygen	sulphur
Makarwal	4.1 – 6.0	44.7 – 66.8	0.2 – 1.2	12.3 – 17.5	2.8 – 6.3
Salt Range	3.6 – 5.3	36.7 – 61.1	0.6 – 1.1	11.4 – 17.5	2.6 – 10.7
Sor Range-Deghari	5.5 – 6.5	61.2 – 64.1	0.9 – 1.4	16.6 – 29.6	0.4 – 5.6
Pir Ismail Ziarat	N. A.	N. A.	N. A.	N. A.	N. A.
Mach	3.5 – 4.9	50.0 – 57.3	1.2 – 1.4	7.5 – 13.0	3.2 – 7.4
Khost-Harnai	3.9 – 6.7	42.4 – 67.3	1.0 – 1.5	7.0 – 16.2	1.4 – 9.4
Duki	N. D.	N. D.	N. D.	N. D.	2.7 – 7.7
Bahlol-Bala Dhaka	N. D.	N. D.	N. D.	N. D.	3.3 – 4.5
Lakhra	5.7 – 7.0	28.8 – 43.0	0.6 – 0.8	29.4 – 47.8	1.8 – 6.5
Sonda	5.0 – 6.0	38.2 – 55.8	0.8 – 1.2	30.4 – 34.5	0.4 – 5.2
Meting	1.8 – 7.1	37.5 – 44.2	0.7 – 0.9	13.3 – 42.3	2.9 – 5.1

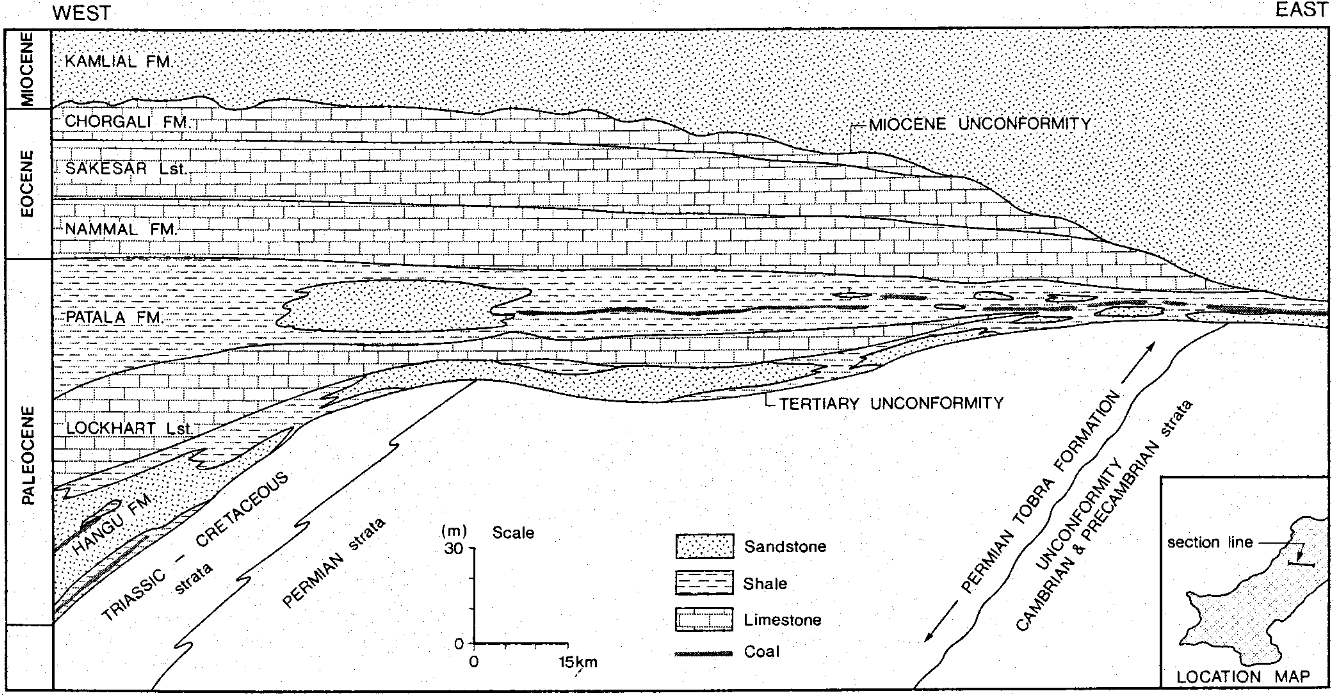


Fig. 7.15. Restored stratigraphic cross section of the coal-bearing sequences of Paleocene and Eocene age in northern Pakistan. Coal bed thickness and dip of pre-Tertiary strata are exaggerated. Datum is the Patala Formation (after WARWICK & SHAKOOR 1988).

The **Makarwal coal field** covers an area of about 75 km^2 and is located 45 km southwest of Kalabagh (32° 58'N; 71° 34'E). Coal crops out in a folded, elongate anticline with a steep overturned eastern limb and 15° to 50° dip on its western limb. A number of faults affect the coal field and cause difficulties in mining. The main coal bed occurs at the base of Hangu Formation and ranges from 0.3 m to 3.0 m in thickness, with an average thickness of about 1.1 m (WARWICK & HUSSAIN 1990). A thin and less persistent coal bed as much as 0.6 m thick is present in the middle part of the Hangu Formation. The annual coal production from Makarwal is about 225,000 t (KAZMI & ABBAS 1991). The coal reserves of this field are estimated at 22 mio. t (WARWICK & HUSSAIN 1990).

The Makarwal coal is of high-volatile B and C bituminous in rank (LANDIS et al. 1971, AHMED et al. 1986). According to HASAN (1990) the maceral contents of this coal consist of vitrinite 71 %, inertinite (18.9 %) and liptinite (9.8 %). Chemical analyses of Makarwal coal are given in Table 7.4 .

The **Salt Range coal field** covers an area of approximately 1,500 km^2 in the central and eastern Salt Range. The northern limit of the coal field is marked by the approximate areal extent of the Eocene limestones (WARWICK & HUSAIN 1990). East to west, the coal field extends for about 100 km and its width ranges from 15 km to 20 km. The coal occurs in the Patala Formation in a synclinal plateau bounded by eroded anticlines. A number of normal faults traverse the area forming small escarpments and repeating exposures of the Patala Formation which could be mined for coal.

There are more than two coal beds in the Salt Range but in most places only one is minable. The maximum thickness of the minable coal bed is about 2.13 m. It commonly contains partings of shale and sandstone. Vertically it is gradational with carbonaceous shale; these beds form discontinuous, northeasterly-trending, elongate bodies, 2 km to 3 km long and 1 km wide (WARWICK & SHAKOOR 1988). Based on 345 bore holes, outcrop and mine thickness data, WARWICK & SHAKOOR (1988) estimated that the average cumulative coal thickness is 43 cm and coal plus carbonaceous shale thickness is 46 cm for the entire coal field.

The rank of the Salt Range coal ranges from high-volatile C to B bituminous (LANDIS et al. 1971); its calorific value ranges from 4,182 to 5,267 kcal/kg. According to HASAN (1990), the maceral contents consist of vitrinite (79.1 %), inertinite (11.2 %) and liptinite (9.7 %). Chemical analyses of the coal are given in Table 7.4 . The annual production is about 225,000 t (KAZMI & ABBAS 1991). The total coal resources were estimated to be about 234 mio. t (WARWICK & HUSAIN 1990; Table 7.3).

Minor coal deposits are found in the Hangu-Karak area in a series of steeply dipping, east trending parallel folds which plunge to the east. On the western side the open ends of the folds form escarpments with outcrops of the Hangu Formation which contains coal. This coal is likely to be a continuation of the Makarwal Coal Field. Coal is being mined on a limited scale. Annual production from this area is about 26,500 t (GAUHAR 1988).

In the Cherat area, coal beds 1.0 m thick are exposed in the folded Patala Formation (GAUHAR 1988). The coal has some lateral extent as indicated by a few bore holes. Limited data indicate that the calorific value is 13,000 BTU; it contains 3.0 % ash and 0.5 % total sulphur. The annual production from Cherat is about 500 t (GAUHAR 1988).

In the Kotli area, the Patala Formation contains two coal beds. The lower bed commonly overlies bauxite and fire clay along the unconformity between Cambrian dolomite and Paleocene sediments. The upper coal bed lies 10 m to 15 m above the lower one. The thickness of these beds ranges from 20 cm to 2.2 m (average 0.6 m). The coal laterally grades into carbonaceous shale. On an average, the coal contains 27.94 % ash, 48.4 % fixed carbon, and 2.14 % sulphur. Recoverable reserves are estimated at 61,000 tonnes (SHAH & BHUTTA 1989, AHMAD 1981).

7.32 Quetta – Harnai – Duki coal region

This coal bearing region covers an area of approximately 12,500 km^2 and extends for about 240 km westward from near Bahlol (30° 01'N; 69° 28'E) in Loralai District to Quetta, and then another 160 km southwards to Johan (29° 20'N; 66° 52'E) in Kalat District (Fig. 7.14). It forms a part of the foreland fold belt and it may be divided into three main structural zones: (1) The Duki zone which comprises its eastern part and is largely composed of east-west trending enechelon broad folds with outcrops of Jurassic to Eocene sedimentary rocks; (2) the Sharigh – Sor Range – Mach zone which forms the central part and is characterised by the extensive gently folded Zarghun synclinal molasse basin, rimmed by Eocene, (coal bearing) and earlier rocks which form tight folds, and (3) the Johan zone which forms the southwestern part and is largely comprised of north-south trending folds in which Jurassic to Eocene rocks are exposed.

Table 7.5. Palaeogene stratigraphic sequence in the coal bearing area of Baluchistan (after SHAH 1990).

Group	Formation	Lithology	Age
	Kirthar Formation	thick bedded to massive, grey to white limestone with interbeds of shale and minor marl	Mid. Eocene to Early Oligocene
	Tio Formation	sandstone, siltstone, conglomerate, claystone and shale with locally developed coal seams	Early Eocene
Ghazij Group	Drug Formation	finely crystalline pebbly limestone with interbedded claystone	Early Eocene
	Shaheed Ghat Formation	greenish, brownish to chocolate coloured claystone with gypsum and marl and minor limestone	Early Eocene
	Dunghan Formation	nodular to massive limestone with subordinate shale, marl, sandstone and limestone conglomerate	Paleocene to Early Eocene

In the Quetta-Harnai-Duki region, coal beds are in the Ghazij Group of rocks of early Eocene age. The general Palaeogene stratigraphy of the coal-bearing region of Baluchistan has been summarized in Table 7.5. According to KAZMI (1962) and SHAH (1990), the lower part of the Ghazij Group was deposited in a sub-littoral off-delta or pro-delta environment whereas the upper part (Toi Formation) formed largely in a deltaic, lagoonal and fluviatile environment.

In the Quetta-Harnai-Duki region, coal production is mainly mined from Sor Range-Deghari, Pir Ismail Ziarat, Mach, Khost-Harnai and Duki areas (Fig. 7.14). Coal deposits also occur in the Bahlol-Bala Dhaka area, east of Duki and near Johan.

The **Sor Range – Deghari coal field** is located 10 km to 20 km east and southeast of Quetta and comprises a northwest trending syncline. This structure is about 22 km long and 4 km wide. The western limb of the syncline has been truncated by the Ush Bul Thrust Fault. A relatively thin sequence of marine sandstone, mudstone and marl of the Nari and Gaj Formations, covered by Neogene molasse, is exposed in the central part of the syncline. The underlying limestone of the Kirthar Formation forms a ridge and a prominent scarp along the northern, eastern and western margins of the syncline. Beneath this scarp, coal mines are clustered along the coal outcrops in the upper part of the Ghazij Group. A prominent bed of conglomerate 12 m to 21 m thick, which grades southward into sandstone, is 30 m–50 m beneath the Kirthar Limestone and serves as a marker horizon. The coal is below this bed.

Several lenticular coal beds ranging in thickness from a few cm to 3 m are present but not more than two are being mined or are minable in any one of the lease areas.

The average coal bed thickness is about 1.2 m (AHMED et al. 1986). The rank of the coal ranges from sub-bituminous B to sub-bituminous A (LANDIS et al. 1971). According to the petrographic research by GHAZNAVI (1988), the Sor Range – Deghari coal contains 83 % - 89 % vitrinite, 4.3 % - 5.7 % inertinite and 6.6 % - 10.8 % liptinite. The calorific value ranges from 4,831 to 6,060 kcal/kg with an average value of 5,644 kcal/kg (SHAH 1990; WARWICK & JAVED 1990). Chemical analyses of the coal are given in Table 7.4. Annual production from this field is about 460,000 t. About 50 mio. t of coal resources have been estimated by SHAH (1990).

The **Pir Ismail Ziarat coal field** is relatively small (area 20 km^2) and is situated 60 km southeast of Quetta and about 15 km north of Mach (29° 52'N; 67° 51'E). It is comprised of a north trending anticline with resistant Jurassic to Paleocene limestones exposed in the core. This core forms a hill surrounded by a depression in which a thick sequence of sandstone, shale and marls of the Ghazij Group crops out. The overlying ridge forming Kirthar Limestone surrounds this depression. The southwestern part of the coal field has been cut off by a large northwest-southeast trending thrust fault. There are two coal beds. The upper bed is 60 cm - 70 cm, the lower one is 40 cm - 45 cm thick. The coal is brownish black to black and breaks with a conchoidal fracture. It is high volatile bitumious C in rank, its moisture content ranges from 5.2 % to 10 %. The heating value ranges from 5,353 to 5,939 kcal/kg. The annual production is about 115,000 t (AHMAD et al. 1986). The coal resources have been estimated at 11.0 mio. t (AHMED et al. 1986). The down-dip extend of coal in this field, especially below the Zarghun syncline to the north, is not known; consequently, the dimensions of the field are probably greater and there may be substantial hypothetical resources.

The **Mach coal field** is spread over an area of about 45 km^2 around the town of Mach. Here, the rocks of the Ghazij Group are present in a large synclinal structure, the greater part of which is covered by alluvial valley fill. The coal-bearing zone of the Ghazij Group (see Chapter 3.41) is about 150 m thick and consists largely of shale and sandstone with subordinate siltstone and limestone. The rocks are tightly folded and show steep dips. There are several coal beds ranging in thickness from 30 cm -1.5 m. Out of these only 3 ot 4 beds (average thickness 75 cm) are workable. The coal is largely blocky and ranks from sub-bituminous C to sub-bituminous B. Its heating values range from 5,100 to 5,730 kcal/kg (AHMED et al. 1986). Chemical analyses are given in Table 7.4 . According to GHAZNAVI (1988), the Mach coal is high in vitrinites (87.8 %), low in inertinites (2.6 %) and liptinites (9.6 %). The average annual coal production from Mach is about 125,000 t. The resources of this coal field are estimated at about 23 mio. t (AHMED et al. 1986).

The **Khost – Harnai coal field** is the largest in Baluchistan and it is located about 160 km ESE of Quetta on the eastern flank of the Zarghun molasse basin, where the steep-dipping Kirthar Limestone forms an extensive northwest-trending ridge. Beneath this ridge marl, shale, mudstone, sandstone and conglomerate of the Ghazij Group are exposed, containing coal in the upper part of the Group. Coal mines are dotted along the ridge for about 40 km, extending from northwest of Khost (29° 12'N; 67° 05'E) to a few kilometers southeast of Harnai. Between Sharigh (30° 14'N; 67° 43'E) and Harnai (30° 06'N; 67° 54'E), the coal beds are in a small (4 km x 24 km) synclinal structure capped by molasse. Coal crops out along the flanks of the syncline and is being mined.

The coal-bearing zone is about 150 m thick. It contains several beds from a few cm to 1.5 m thick but only three of these, known as the top, middle and the bottom seams, are being mined. These beds commonly range in thickness from 0.6 m - 1.0 m. The top seam has the maximum lateral extent and its thickness varies from 0.5 m - 0.9 m though at places (Khost area) it is as much as 3.5 m thick (AHMED et al. 1986, SHAH 1990).

The Khost-Harnai coal ranges in rank from lignite to bituminuous B. The average rank is sub-bituminous C to A. Its heating values range from 4,420 to 7,000 kcal/kg. It contains about 83 % vitrinites, 1.8 % to 4.7 % inertinites and 11.6 % to 15 % liptinites (GHAZNAVI 1988). Chemical analyses of the coal are given in Table 7.4 . The average annual production of coal from this field is about 100,000 t and the total coal resources have been estimated at about 76 mio. t (Table 7.3).

The **Duki coal field** is near the town of Duki (30° 09'N; 68° 34'E) in Loralai District, about 320 km east of Quetta (Fig. 7.14). The coal is in a moderately-dipping, east trending, asymetrical syncline, 30 km long and 5 km to 10 km wide. Rocks of the Ghazij Group crop out in the syncline, though most of its central part is covered with alluvium. Coal is being mined on both limbs of the syncline. The coal bearing zone is about 550 m thick and contains claystone, siltstone and sandstone with lesser amount of marl. There are 17 beds out of which 15 are being worked. However only five of these are 0.5 m or more thick (AHMAD et al. 1985, KHAN et al. 1987, SHAH 1990).

The Duki coal is brownish to black, blocky, lumpy and laminated. Its rank ranges from high sub-bituminous B to C, though sub-bituminous A and even lignite are present (KHAN et al. 1987). The heating values range from 4,610 to 6,380 kcal/kg (AHMED et al. 1986). Its maceral composition is 84.4 % to 87.4 % vitrinites, 2.4 % to 3.2 % inertinites and 6.4 % to 12.8 % liptinites (GHAZNAVI 1988). Chemical analysis of Duki coal is given in Table 7.4. The average annual production of coal from Duki is around 250,000 t. The coal resources of this field are estimated at about 50 mio. t (Table 7.3).

7.33 Lower Sindh coal region

An extensive coal basin forms a large part of the Kirthar area of the Lower Indus Basin in Sindh. It extends westward from near Chachro (25° 40'N; 70° 15'E) in the Thar Desert (the Thar Coal Field was described recently by FASSETT & DURRANI (1994); their detailed investigations were not integrated in Chapter 7.) through the Badin (24° 40'N; 68° 50'E) area to the Lakhra-Sonda-Thatta area (Fig. 7.14). The western part of the basin (west of the Indus) falls in the fold belt zone, whereas most of the eastern part of the basin covers the platfrom slope. Platform shelf and carbonate deposits ranging in age from Triassic to Recent overlie the basement slope. The rock formations dip gently westward though disrupted by a series of deep seated normal faults. In the fold belt region, these rocks form gently dipping folds.

Presently three coal fields are known which have been explored, namely the Lakhra, the Sonda and the Meting coal fields. In the Lakhra – Sonda area (24° 59'N; 68° 08'E), Thatta (24° 45'N; 67° 55'E), Meting (25° 10'N; 68° 7'E) and Tando Mohammad Khan (25° 08'N; 68° 32'E) areas, the limits of the coal fields have been partially delineated through a large number of exploratory holes (KAZMI et al. 1990). In the Badin area east and southeast of Tando Mohammad Khan, a number of oil exploration wells

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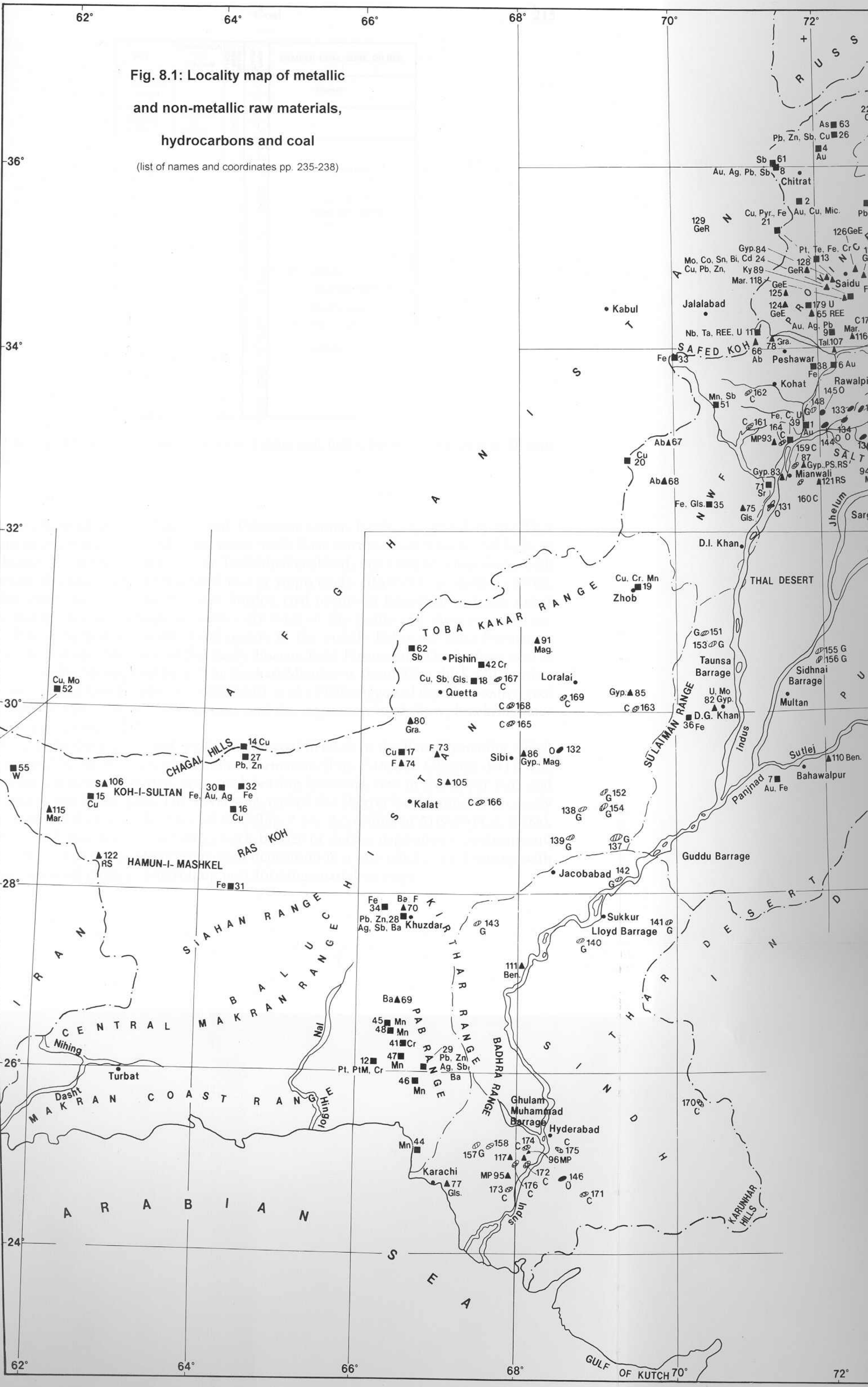
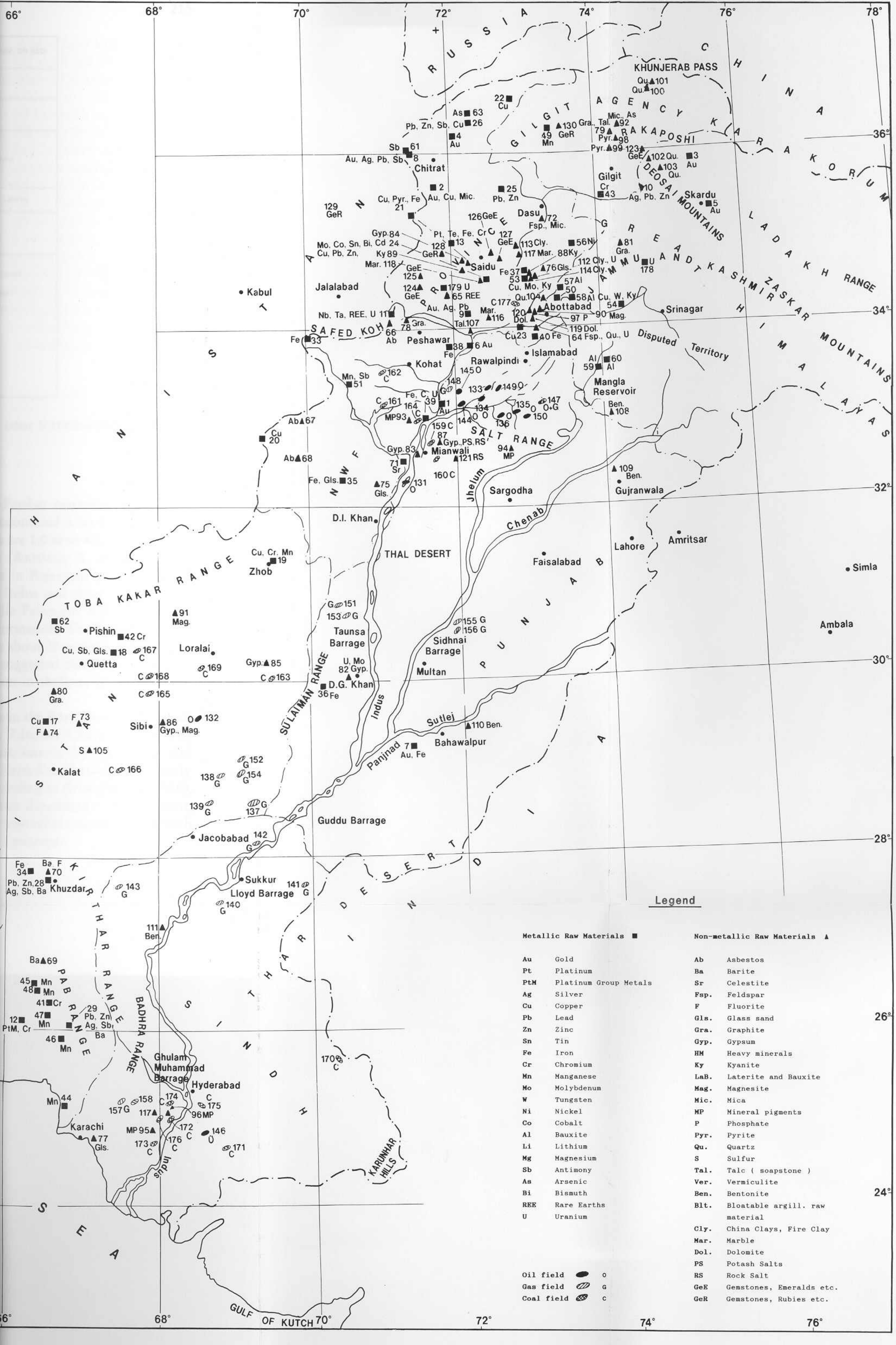


Fig. 8.1: Locality map of metallic and non-metallic raw materials, hydrocarbons and coal

(list of names and coordinates pp. 235-238)



Legend

Metallic Raw Materials ■	
Au	Gold
Pt	Platinum
PtM	Platinum Group Metals
Ag	Silver
Cu	Copper
Pb	Lead
Zn	Zinc
Sn	Tin
Fe	Iron
Cr	Chromium
Mn	Manganese
Mo	Molybdenum
W	Tungsten
Ni	Nickel
Co	Cobalt
Al	Bauxite
Li	Lithium
Mg	Magnesium
Sb	Antimony
As	Arsenic
Bi	Bismuth
REE	Rare Earths
U	Uranium

Non-metallic Raw Materials ▲	
Ab	Asbestos
Ba	Barite
Sr	Celestite
Fsp.	Feldspar
F	Fluorite
Gls.	Glass sand
Gra.	Graphite
Gyp.	Gypsum
HM	Heavy minerals
Ky	Kyanite
LaB.	Laterite and Bauxite
Mag.	Magnesite
Mic.	Mica
MP	Mineral pigments
P	Phosphate
Pyr.	Pyrite
Qu.	Quartz
S	Sulfur
Tal.	Talc (soapstone)
Ver.	Vermiculite
Ben.	Bentonite
Blt.	Bloatable argill. raw material
Cly.	China Clays, Fire Clay
Mar.	Marble
Dol.	Dolomite
PS	Potash Salts
RS	Rock Salt
GeE	Gemstones, Emeralds etc.
GeR	Gemstones, Rubies etc.

Oil field	●	O
Gas field	▨	G
Coal field	▨	C

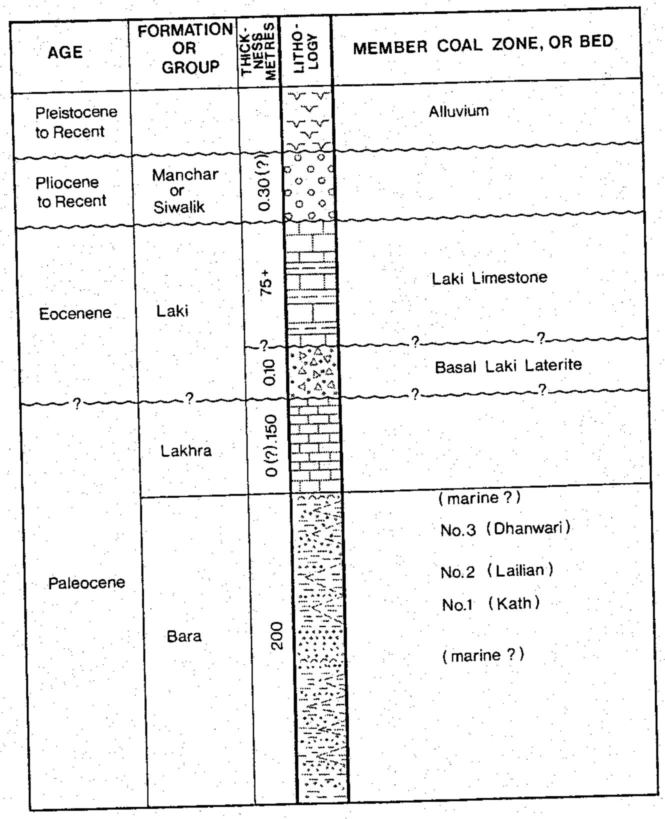


Fig. 7.16. Generalized stratigraphic section of Lakhra coal field (after SCHWEINFURTH & HUSAIN 1988).

have encountered coal in Eocene and Paleocene strata. Farther eastward in the Thar Desert near Chachro, two shallow water wells have encountered 5 to 6 coal beds at depths ranging from 145 m to 297 m. Individual coal beds are 1.0 m to 4.6 m thick, with aggregate thicknesses of 11.9 m and 16.1 m respectively (RAHMAN & AHMAD 1990). Farther eastward across the Pakistan border, coal occurs in Rajasthan in India and is being mined. Rock outcrops are seen only west of the Indus and these range in age from Paleocene to the Recent. Coal occurs in the middle Paleocene Bara Formation and in the Sonhari Member of the Early Eocene Laki Formation. The Sonhari coal is restricted to the Meting coal field. The Sonhari Member is about 30 m thick and consists of sandstone and lateritic clay. OUTERBRIDGE et al. (1989) suggested that the Sonhari coal was deposited in a coastal environment and the vegetation in shallow, brackish-water swamps formed this coal.

The coal in the Lakhra and Sonda-Thatta coal fields is in the Bara Formation which is conformably overlain by the Lakhra Formation (Fig. 7.16; see Chapter 3.41). The Bara Formation contains two main coal bearing horizons, one in the upper part and the other in the lower part. The lower one, named the Jherruck coal zone, is presently known only in the Sonda-Thatta coal field (Fig. 7.14). According to AHMAD et al. (1986), the Bara coal was formed in limnic, back-barrier or deltaic depositional environment, though SANFILIPO et al. (1990) suggested deposition in a low relief coastal setting with eustatic sea level changes controlling peat forming coastal swamps.

The **Lakhra coal field** is the most intensely studied and explored field of Pakistan. More than 244 test holes have been drilled in this field, which is located about 20 km to 25 km northwest of Hyderabad (Fig. 7.14), and covers an area of approximately 300 km^2. Structurally, the coal field comprises a broad, gently folded anticline (dips around 5°), which has been dissected by several normal faults (1.5 m to 9 m throws). Coal is in the Bara Formation, 50 m to 150 m below surface. A number of beds have been encountered in bore holes. Nine of these are more persistent (Schweinfurth & Husain 1988), three are of greater economic significance. In descending order they are known as the Dhanwari, the Lalilian and the Kath seams (Fig. 7.16). Pertinent information about these beds is given in tables 7.3 and 7.4 . The Lakhra coal is dull black and contains amber and resin flakes, and clay and gypsum partings. It tends to crumble on long exposure and is susceptible to spontaneous combustion. Petrographic studies by Ghaznavi (1988) show that the Lakhra coal contains 54.3 % to 77.4 % huminite, 12.4 % to 26.7 % inertinite and 10 % to 27 % liptinite macerals. The rank of the coal ranges from lignite A to sub-bituminuous C. Its heating value ranges from 2,570 to 4,260 kcal/kg. More detailed information concerning coal quality and chemical analysis are given in Table 7.6. The average annual production of coal from Lakhra is about 300,000 t. The coal reserves of Lakhra have been estimated to be about 1,592 mio. t (Table 7.3).

Table 7.6. Data and analytical results of major coal beds of Lakhra coal field (after Ahmed et al. 1986).

Lakhra coal field coal beds	Dhanwari	Lailian	Kath
depth (m)	43 – 90	26.8 – 122.8	66 – 107
thickness (m)	0.1 – 2.94	0.75 – 3.35	0.1 – 1.4
extent (km^2)	18	180	6
volatile matter	38.8 – 47.6	37.3 – 45.1	43.5
fixed carbon	14.5 – 24.5	32.3 – 38.3	34.6
sulphur	6.9 – 8.5	2.3 – 8.3	9.8
ash	14.5 – 24.5	10.8 – 27.4	22.1

The **Sonda coal field** is by far the largest coal field in Pakistan and is located just south of the Lakhra coal field between the towns of Thatta and Sonda, east of Karachi. It continues for about 100 km northeastward from Thatta along the Indus River and covers an area of more than 1,400 km^2. It extends eastward across the Indus to Tando Mohammad Khan and beyond (Fig. 7.14). Its trans-Indus extension has been referred to by some workers as Indus East coal field (Tohmas & Khan 1990).

The Sonda coal field comprises a nearly flat (dip 2° or less) north-trending anticlinal structure (Schweinfurth & Husain 1988). Coal is in thick lenses of siltstone and mudstone of the Bara Formation. More than 29 coal beds of varying thickness and continuity, occurring at different stratigraphic intervals, have been encountered in various test holes. The coal beds are lensoid and their correlation is difficult due to their pronounced pinching and swelling. Subsurface bore hole data show that the coal is relatively more persistent at three main intervals (Ahmad et al. 1986) which have

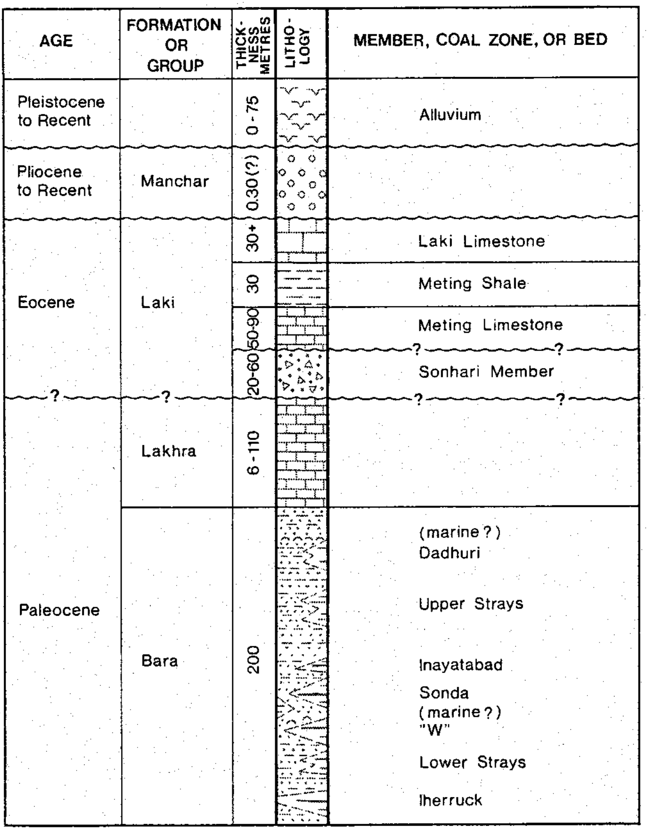


Fig. 7.17. Generalized stratigraphic section of Sonda coal field (after SCHWEINFURTH & HUSAIN 1988).

been named as Dadhuri, Sonda and Jherruck coal zones (Fig. 7.17). In between the above mentioned three main coal zones, four other (but minor and less persistent) zones referred to as "Upper Strays", "Inayatabad", and "Lower Strays" have been identified (SCHWEINFURTH & HUSAIN 1988). These minor coal zones consist of one or more recognizable coal beds separated by relatively persistent partings of sandstone or shale.

The Sonda coal zone contains the thickest and most persistent coal bed, though at places the bed splits into thinner layers and becomes discontinuous or changes to carbonaceous shale (Table 7.7). Near Jherruk, the cumulative thickness of coal reaches 9 m, and the coal in the Sonda coal zone attains an average of 6.2 m (KAZMI et al. 1990).

According to AHMAD et al. (1986), the Sonda coal was deposited on a lower deltaic plain. SANFILIPO et al. (1990) have pointed out that the clean sandstones associated with the coal zone lack obvious scouring and contain abundant glauconite, burrows and marine fossils. This feature suggests marginal marine conditions for the Bara Formation. Isopac maps and subsurface cross-sections by KAZMI et al. (1990) show clay plugs and sinuous buried channels, suggesting that the formation of coal was associated with near shore palaeo-channels and swamps. Coal petrology data (high ulminite, textinite and well preserved homodetrinite) indicate that the Sonda coal formed in swamps with vegetal matter derived from alluvial or upper deltaic plain (HASAN 1990).

Table 7.7. Data and analytical results of coal samples from major coal beds of Sonda coal field * (after AHMED et al. 1986).

Sonda coal field * coal beds	Dadhuri	Sonda	Jherruk
depth (m)	43 – 57	100 – 160	195 – 240
thickness (m)	0.1 – 0.7 (0.48) (9)	0.4 – 6.2 (1.12) (20)	0.86 (2)
moisture	11.28 – 44.85 (18.51) (9)	12.56 – 39.48 (20.73) (17)	14.79 – 17.32 (16.05) (2)
volatile matter	17.76 – 33.5 (24.39) (8)	15.94 – 36.68 (31.66) (17)	26.69 – 27.31 (27.00) (2)
fixed carbon	17.06 – 46.42 (30.33) (8)	25.97 – 53.05 (37.53) (16)	36.88 – 42.09 (39.48) (2)
sulphur	3.42 – 5.84 (4.30) (8)	0.56 – 5.29 (2.7) (17)	3.51 – 3.54 (3.52) (2)
ash	8.75 – 28.57 (20.66) (8)	3.96 – 30.08 (13.29) (17)	13.90 – 21.02 (17.86) (2)

* figures in parentheses indicate (i) average value and (ii) number of samples

The Sonda coal ranks from lignite A to sub-bituminous C (SCHWEINFURTH & HUSAIN 1988). Its heating value ranges from 3,600 to 5,700 kcal/kg (AHMAD et al. 1986). Detailed chemical analysis of the coal is given in Table 7.4. Based on subsurface data from bore holes the coal resources of Sonda coal field have been estimated at about 7,300 mio. t (Table 7.3). The eastern extension of the coal field has not yet been explored. The coal resources of Sonda are thus likely to be much higher.

The **Meting coal field** is relatively small and covers an area of about 90 km^2 east of the railway line between Meting and Jhimpir (25° 01'N; 68° 01'0E) railway stations (Thatta District; Fig. 7.14). The coal is in the Sonhari Member of the Laki Formation of Eocene age, near the contact with the Upper Paleocene Lakhra Formation (Fig. 7.16). There is only one workable coal bed which is commonly thin and lenticular and ranges in thickness from 0.3 m to 1.0 m with an average of 0.5 m. It dips gently westward. The Meting coal ranges from high volatile bituminous C to high volatile bituminous B. Its moisture contents range from 26.6 % - 36.6 %, volatile matter 25.2 % - 34.0 %, fixed carbon 24.1 % - 32.2 %, ash 8.2 % - 16.8 % and its heating value 3,740 to 4,260 kcal/kg (AHMED 1986).

The average annual production of coal is about 40,000 t. The total coal reserves of Meting based on a cut off thickness of 0.6 m and depth of 50 m is about 161 mio. t (KAZMI & ABBAS 1991).

7.4 Nuclear fuels

(FAIZ AHMAD SHAMS, FRITZ BARTHEL and H. FOHSE)

Since the first discovery of uranium minerals in heavy mineral concentrates at Darband (34° 20'N; 72° 52'E) along the Upper Indus River (SHAMS 1955, SHAMS & ZESCHKE 1956, ZESCHKE 1959, REINEMUND 1959), extensive uranium exploration has been carried out by the Atomic Energy Minerals Centre of the Pakistan Atomic Energy Commission (IUREP 1980). The discovered uranium deposits and occurrences can be grouped according to their geological settings (MOGHAL 1974, SHAMS 1983, BUTT 1989 a, BAIG 1990) as follows:

- Granitic rocks
- Alkaline and carbonatite rocks
- Anatectic and migmatic rocks
- Graphitic metapelites
- Sandstones
- Placers
- Surficial deposits

Granitic rocks

Remobilized Cambrian granites of northern Pakistan were considered by SHAMS (1983) as favourable host rocks for primary uranium mineralization. He proposed a model of enrichment of uranium in the upper parts of granitic bodies based on plate tectonic considerations (e.g. Hazara granite). BUTT (1989 a) also discussed the suitability of these granites. He proposed a subdivision into granitic gneisses (Nanga Parbat, Mansehra, Swat), peralkaline granites (Warsak, Malakand, Ambela, Tarbela), all occurring within the Indo-Pakistan Plate between the Main Mantle Thrust in the north and the Main Boundary Thrust in the south (Fig. 7.18), and calc-alkaline granites of the Karakorum batholith north of the Main Karakorum Thrust. The S-type granitic gneisses are Precambrian to Cambrian in age, whereas the other granites are related to the Himalayan orogeny (Cretaceous to Tertiary). The crustal-derived Cambrian and older granites are considered to be the most favourable prospects within the suite of intrusive granites (SHAMS 1983).

Uranium occurrences within the contact aureole of the Ilum granitic gneiss at Karakar (Swat District) were described as quartz-uranothorite veins, uranothorite-sulphide-monazite veins and additional contact mineralizations (BUTT 1989 a), evidently dominated by thorium over uranium. In the Mansehra granite gneiss of the Ahl (34° 32'N; 73° 09'E) area, secondary uranium mineralization is present in shear zones of the altered rock. Additionally, uranium was observed in Pleistocene sands and clays overlying the granite gneiss. According to BUTT (1989 a), their uranium content is 0.03 % U_3O_8; in places, where carbonaceous clays appear, their uranium content reaches 0.2 % U_3O_8. Detailed studies (BUTT 1989 b) have shown that the uranium, which was leached from the granite gneiss by groundwater, was precipitated in clays and sands enriched in organic material. Secondary processes may have led to uranium enrichment

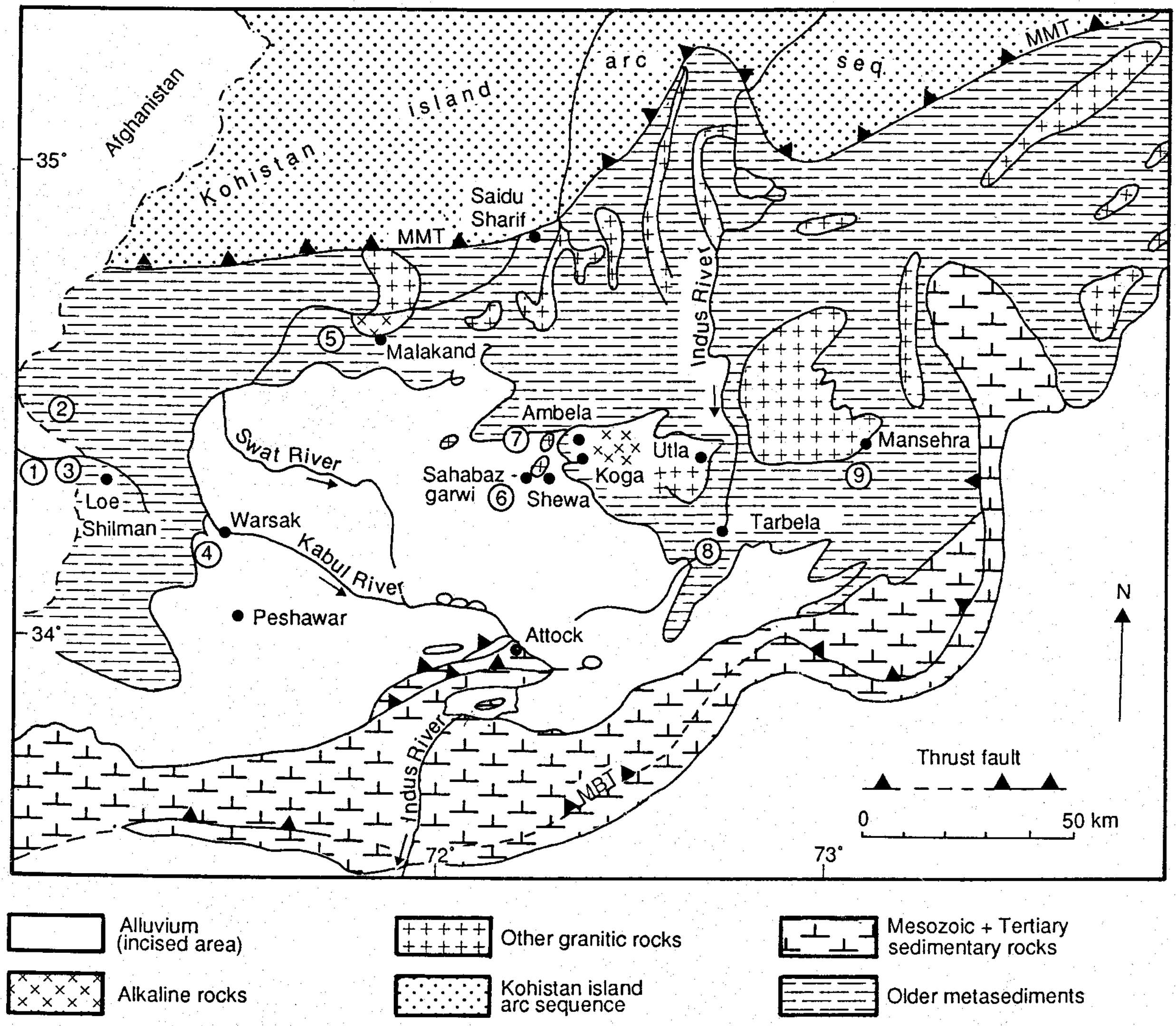


Fig. 7.18. Geological sketch map of Northern Pakistan, showing the Main Boundary Thrust (MBT) and Main Mantle Thrust (MMT). Numbers 1 – 9 indicate locations of alkaline rocks with or without carbonatites (after BUTT 1989 c).

in fractured parts of the granite gneiss. Radioactive minerals have been reported from many pegmatites associated with intrusive Cambrian granites. For instance, pegmatites of Rajdhwari (34° 40'N; 73° 08'E), known for beryl and feldspar production, contain billibinite as dark-brown to black crystals, although only 3 out of 75 pegmatites contain this mineral (SHAHID 1964). Pegmatites of Bunji (34° 40'N; 74° 39'E) contain uraninite, and so do some pegmatites of Darel, Tangir and Baltistan.

Alkaline and carbonatite rocks

Alkaline granites, syenites, albitites and carbonatites were intruded into Precambrian metasediments along fault zones, emplaced during rifting and crustal extension as a result of compression release or tension relief following collision impact (KEMPE 1983). These igneous rocks crop out in northern Pakistan along the Indo-Pakistan Plate margin south of the Main Mantle Thrust (Figs. 2.4, 7.18).

Special attention was given to carbonatites with apatite, rare earth elements (REE), and pyrochlore. The Loe Shilman carbonatite in the Khyber Agency is associated with syenitic intrusions, lamprophyres and hydrothermal veins (BUTT 1989 a). The main uranium mineral is pyrochlore in isolated patches in the amphibole-carbonatite. According to metallurgical studies (SHABBIR et al. 1976), the average uranium grade of the carbonatite ore is about 200 ppm U. Pressure leaching at elevated temperatures yielded a recovery of 78 %. The pyrochlore, as the sole uranium mineral, has about 35 % U, 22 % Nb and 7 % Ta. Another carbonatite at Sillai Patti, about 35 km west of Dargai (34° 28'N; 71° 54'E), Malakand Agency, contains pyrochlor in several layers. The grades range between 0.1 % and 0.2 % U_3O_8 (BUTT 1989 a).

Anatectic and migmatic rocks

A number of uranium concentrations have been reported in migmatites of the Nanga Parbat, Thakot, and Parachinar areas (BUTT 1989 a). At Thakot, at the border of the Mansehra and Swat districts, pegmatoid rocks of different ages are present in a complex suite of metasedimentary rocks (pelitic and psammitic schists, garnet-mica-schists, marbles, talc-schists, quartzites, amphibolites and graphitic schists). Uranium is both disseminated within the biotite pegmatoid rocks and in vein type mineralization (uraninite with sulphides). The grades are too low and irregular to be of economic interest. At Parachinar, uranium mineralization in accessory allanite is in altered granite and migmatized rocks (anatectic granites and pegmatites). The exact nature of the small showings has not been investigated (BUTT 1989 a).

Graphitic metapelites

Pelitic metasediments of Precambrian age in northern Pakistan have been subject to uranium prospecting. Strong radioactivity was observed in pyrite-bearing graphitic schists in the Reshian area; ESE of Muzaffarabad in Azad Kashmir, and in the Kaghan Valley (BUTT 1989 a). In Azad Kashmir, the uranium-hosting Salkhala Formation consists of pelitic schists interbedded with quartzitic schist, both enclosing graphitic schist, that bears characteristically very fine-grained quartz, ubiquitous pyrite and abundant carbonaceous material. Brannerite, xenotime and secondary uraniferous limonite are the main uranium minerals (RAHMAN 1980, BUTT 1989 a). Extensive leaching due to weathering of pyrite has been observed, resulting in strong radioactive disequilibrium (high radioactivity of the graphitic schists corresponds with very low chemical uranium contents). There is some reason to expect that this negative surface expression does not count for the deeper buried bed rock equivalents. Taking this into account, the graphitic schists should bear an interesting uranium potential in northern Pakistan, and their favourability may be enhanced especially towards areas of granitization and igneous activities.

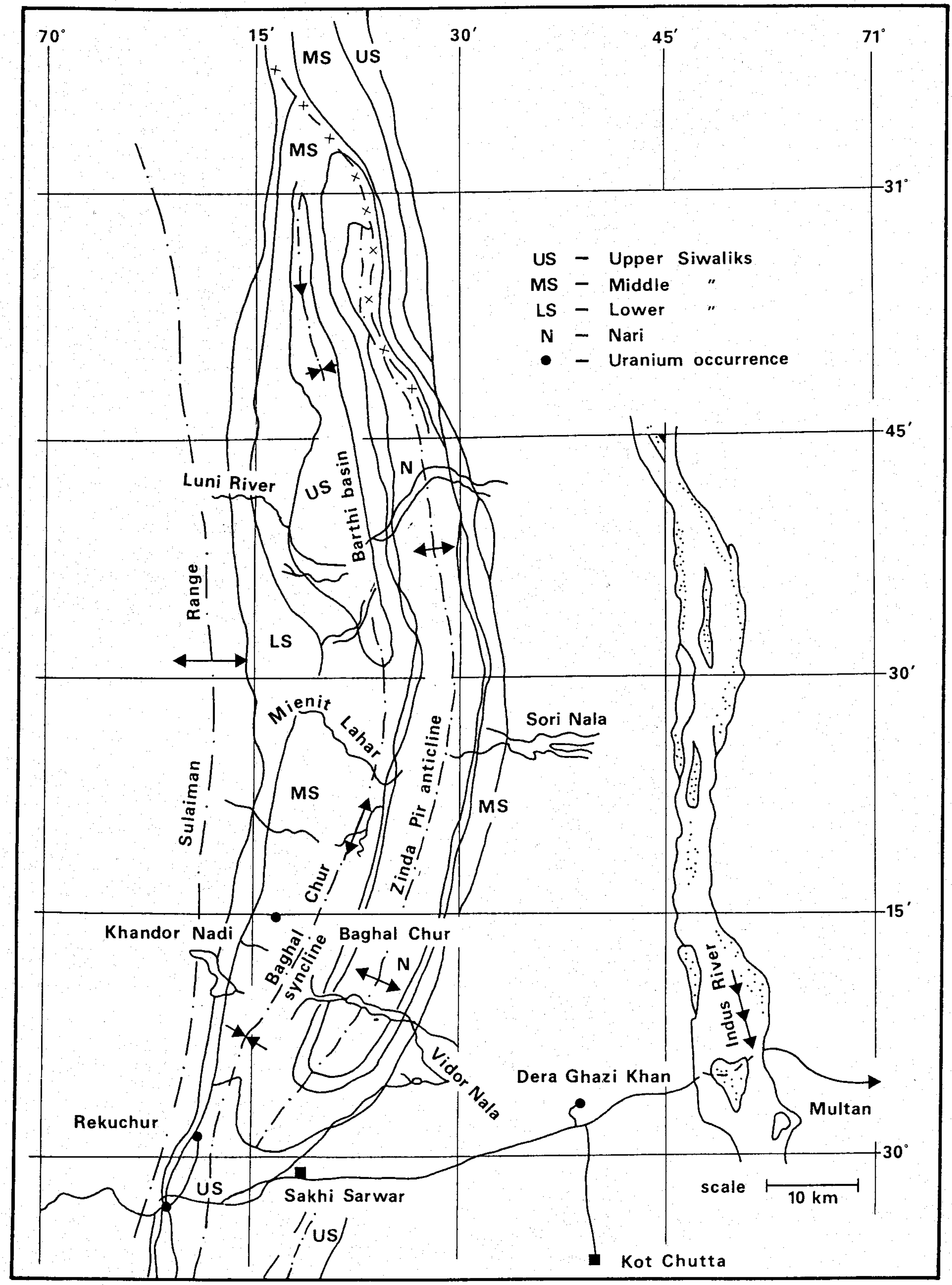


Fig. 7.19. Geological sketch map of Baghal Chur area (after MOGHAL 1974, p. 386).

Sandstones

Uranium mineralization in the molasse-type sandstones of the Siwalik Group (Middle Miocene to Lower Pliocene) has been known since 1959 (MOGHAL 1974). Extensive exploration led to the discovery (1959) by J. A. REINEMUND, F. SPENCER and ABU BAKR of the uranium deposits of Baghal Chur, west of Dera Ghazi Khan (30° 04'N; 70° 38'E), in the eastern flank of the Sulaiman Range (Fig. 7.19). Recently, remobilized uranium deposition has been reported in the Dhok Pathan Formation of the Siwalik Group in the Bannu District, N W F P (BAIG 1990).

The Siwalik Group (see Chapter 3.4) forms part of a large depositional system laid down without major breaks in a narrow southern foredeep of the rising Himalayas. Radioactive anomalies and uranium mineralization have been reported not only from the Siwaliks in Pakistan but also from their eastward continuing equivalents through India, Nepal and Bangladesh.

The Dhok Pathan Formation (Middle Siwalik) is the most important sequence for uranium mineralization. It is composed mainly of thick massive layers of coarse micaceous, greyish to rarely yellowish, sandstones interbedded with grey to drab or brownish clays and shales. Most of the sandstones are still in an unconsolidated state providing good permeabilities. They commonly include calcareous concretions containing several percent carbonate. According to BAIG (1990), volcanic components (ash-fall tuffs) and their decomposition products contributed to the composition of the sandstones and shales as well. In the Bannu Depression (Fig. 7.2), a 10 m–20 m thick pebbly layer of volcanic material is composed of tuff, ash fragments and small particles of volcanic glass. This evidence of synsedimentary volcanic activities has opened reconsideration as to the prime uranium source. The volcanic ejecta provided a good carrier of leachable uranium of close provenance. Yet the detrital arkosic material from the more remote Himalayas might have also contributed as a source (MOGHAL 1974).

At Baghal Chur (Fig. 7.19), uranium mineralization appears in several small elongated lenses and amoeba-shaped masses (Fig. 7.20). The host rock is about 50 m thick, light grey and mostly medium- to fine-grained sandstone with gritty to conglomeratic intercalations (Baghal Chur sand). It is confined on top and bottom by relatively thick shale beds. The whole series is gently inclined at about 10 ° southeast on the eastern flank of the Sulaiman Range. To the east, another roughly north-trending anticline (Zinda Pir anticline) forms a structural barrier, forming a synclinal depositional setting in between (Baghal Chur syncline). Most of the lensy to patchy ore bodies lie above the water table in an oxidizing environment. The uranium mineralization is mainly composed of metatyuyamunite while the unoxidized minerals, uraninite and/or coffinite, are present near or below the water table (BASHAM & RICE 1974). The lateral extension of the ore lenses ranges between 1 m to 30 m at 0.3 m and 2.5 m thickness. The ore-grade mineralization reaches to depths over 150 m (Fig. 7.20).

The delineated ore is of low grade ranging from 0.03 to 0.1 % U_3O_8 (Nuclear Fuel Dec. 1986), but grades over 0.5 % U_3O_8 have been also reported (MOGHAL 1974). The reserve base is estimated to be approximately 100 t uranium but the overall resource potential may be much higher. Mining operations are performed by conventional open pitting and some underground work at depths over 150 m.

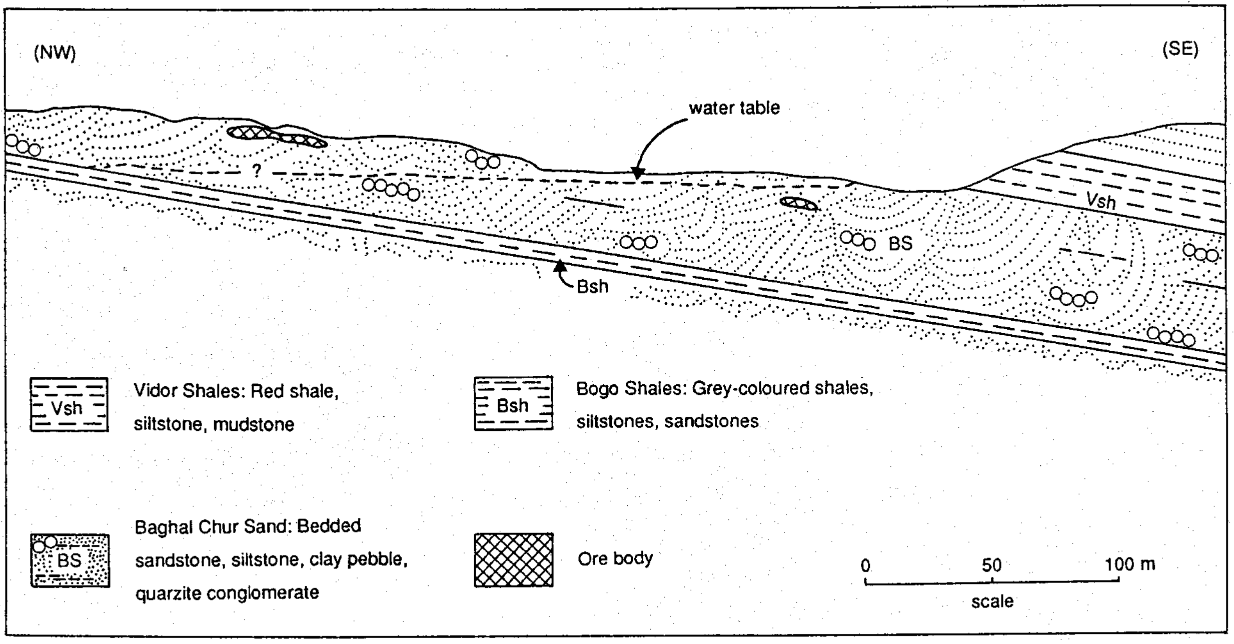

(NW)
(SE)
water table
?
Vsh
BS
Bsh
Vsh
Vidor Shales: Red shale, siltstone, mudstone
Bsh
Bogo Shales: Grey-coloured shales, siltstones, sandstones
BS
Baghal Chur Sand: Bedded sandstone, siltstone, clay pebble, quarzite conglomerate
Ore body
0
50
100 m
scale

Fig. 7.20. Geological cross-section, Baghal Chur area (after MOGHAL 1974, p. 390).

Other uranium concentrations south of Baghal Chur (e.g. Nangar Nai, Rajanpur), and in the Bannu Depression in the north, are still under investigation. The Qubul Khel locality at the eastern margin of the Bannu Depression gives an example of an uranium ore body recently mobilized as a result of uplift movements and exposition under an oxidizing regime (BAIG 1990). The uranium was leached by meteoric waters and migrated downdip along the sandstone-shale contact, thereby mineralizing it with impregnating or fracture-filling uranophane and carnotite. Most of the uranium has been re-precipitated as pitchblende and subordinate coffinite, below the lowered new ground water table under reducing conditions. Owing to the young age of remobilization and redeposition, the radiometric signatures reflect a very high degree of disequilibrium between the site of the leached uranium ore (unmobilized radioactive daughter products much in excess) and the locus of the young uranium accumulation (very weak radiometric expression).

Placers

Placers of the River Indus and its northern tributaries have been washed for gold since time unknown. The residues of heavy mineral concentrates always contain radioactive minerals. Such a concentrate at Darband (34° 20'N; 72° 52'E) contains on average 0.9 % uraninite, 4.0 % monazite, 2.2 % scheelite, REE minerals and other minerals. Sand from river terraces contains on average 0.001 % U_3O_8, although wind-sorted sands may have more than 0.006 % U_3O_8. In the Attock Plain, N W F P, uraninite is present in deposits of micaceous silt in natural levees, containing about 0.0024 % U_3O_8 and 0.019 % ThO_2. At Kalabagh (32° 58'N; 71° 33'E), Punjab Province, purple sand and silt beds, averaging

12 cm thick, yield heavy mineral concentrate with an average 0.004 % uraninite (0.006 % U_3O_8) and 0.149 % monazite (0.081 % ThO_2; MILLER 1962).

Notably, placers of the River Indus and its tributaries in northern Pakistan are mostly uraniferous: Haramosh – Skardu section, 0.005 % - 0.0255 % U_3O_8; Skardu – Oldhang section, 0.045 % U_3O_8; Shigar valley section, 0.062 % U_3O_8; Astor valley section, 0.015 % U_3O_8; Hunza valley section, 0.0215 % U_3O_8; Kunhar valley section, 0.0025 % U_3O_8; Chitral valley section, 0.0019 % U_3O_8 (ZAKI et al. 1976).

Surficial deposits

Favourable environments for surficial uranium mineralization of calcrete-type are the semi-desert basins in southeastern Pakistan. Essentially, the arid and extremely dry conditions in closed basins, coupled with shallow groundwater movement and nearby uranium sources, led to mineral enrichment by evaporation processes. Of the two regions investigated, the Cholistan area proved the presence of uraniferous calcrete mineralization, whereas calcrete development in the Thar Parkar Desert lacks uranium enrichment (MOGHAL 1988).

7.5 Geothermal energy resources

(ALI H. KAZMI)

Most of the high enthalpy geothermal resources of the world are within seismic belts associated with zones of crustal weakness such as plate margins and centers of volcanic activity. A global seismic belt passes through Pakistan and the country has a long geological history of geotectonic events: Permocarboniferous volcanism (Panjal traps in Kashmir) as a result of rifting of Iran-Afghanistan microplates (SILLITOE 1978), Late Jurassic to Early Cretaceous rifting of the Indo-Pakistan Plate (POWELL 1979), widespread volcanism during Late Cretaceous (Deccan traps) attributed to the appearance of a "hot spot" in the region, emergence of a chain of volcanic islands along the margins of the Indo-Pakistan Plate (KAZMI 1979a, DEJONG et al. 1979), collision of India and Asia (Late Cretaceous – Paleocene) and the consequent Himalayan upheaval (POWELL 1979), and Neogene – Quaternary volcanism in the Chagai District.

This geotectonic framework suggests that Pakistan should not be lacking in commercially exploitable sources of geothermal energy. This view is further strengthened by the fairly extensive development of alteration zones and fumeroles in many regions of Pakistan, presence of a fairly large number of hot springs in different parts of the country, and indications of Quaternary volcanism. These manifestations of geothermal energy are found within the following three geotectonic or geothermal environments:

- Geopressurised systems related to basin subsidence,
- seismotectonic or suture-related systems,
- systems related to Neogene-Quaternary volcanism.

7.51 Geopressurised systems

In geopressurised systems the normal heat flow is trapped by insulating impermeable beds in a rapidly subsiding sedimentary basin (ARMSTEAD 1978). It is on account of their great depth (as much as 6,000 m) that temperatures ranging from less than 93 °C to more than 150 °C are encountered. They commonly contain pressurised hot connate water at pressures ranging from 40 % to 90 % in excess of the hydrostatic pressure corresponding

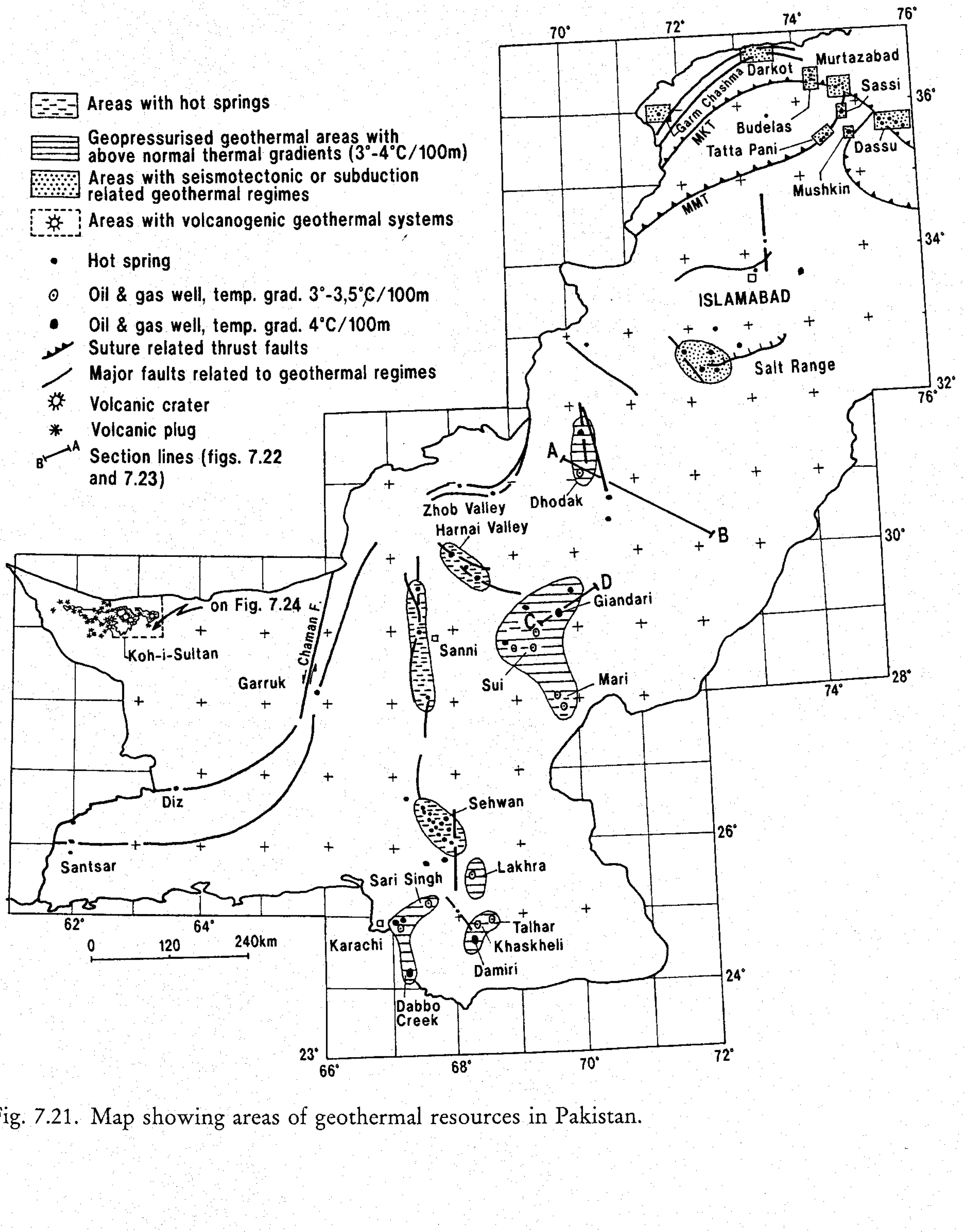

Areas with hot springs
Geopressurised geothermal areas with above normal thermal gradients (3°-4°C/100m)
Areas with seismotectonic or subduction related geothermal regimes
Areas with volcanogenic geothermal systems
Hot spring
Oil & gas well, temp. grad. 3°-3,5°C/100m
Oil & gas well, temp. grad. 4°C/100m
Suture related thrust faults
Major faults related to geothermal regimes
Volcanic crater
Volcanic plug
Section lines (figs. 7.22 and 7.23)
A
B
70°
72°
74°
76°
36°
34°
32°
30°
28°
26°
24°
23°
62°
64°
66°
68°
Murtazabad
Darkot
Garm Chashma
Sassi
MKT
Budelas
Tatta Pani
Dassu
Mushkin
MMT
ISLAMABAD
Salt Range
Dhodak
Zhob Valley
Harnai Valley
D
Giandari
C
Sanni
Sui
Mari
on Fig. 7.24
Chaman F.
Koh-i-Sultan
Garruk
Diz
Santsar
Sehwan
Lakhra
Sari Singh
Talhar
Khaskheli
Damiri
Karachi
Dabbo Creek
0
120
240km

Fig. 7.21. Map showing areas of geothermal resources in Pakistan.

to the depth. Gradual subsidence has led to the ultimate isolation of trapped pockets of water contained in alternating pervious and impervious sequences.

In Pakistan such geopressure zones are present in southern Sindh and offshore areas of Sindh, along the western margin of the Indus Plain and in the Potwar Basin (Fig. 7.21). Presently available information indicates three main geothermal zones in the Indus Basin. These are the South Sulaiman, South Kirthar, and Lower Indus zones, which are briefly described below.

The **South Sulaiman geothermal zone** comprises the southernmost part of the Sulaiman Foredeep, and a part of the adjacent Mari-Bugti fold belt and the Mari-Khandkot High (Fig. 7.1; Kazmi & Rana 1982). In this region the Giandari oil and gas well encountered an abnormally high thermal gradient of 4.1 °C/100 m (Khan & Raza 1986). Likewise, the neighbouring oil and gas wells at Sui (to the southwest) and at Mari (to the south) have also recorded higher than normal geothermal gradients of about 3.0 to 3.49 °C/100 m. Farther northward the well at Dhodak has a similar thermal gradient. In this region, thermal springs have been recorded (Oldham 1882, Bakr 1965), at Uch (28° 45'N; 68° 40'E), Garm Ab at the foot of Mari Hills (29° 33'N; 69° 40'E), Zinda Pir (30° 25'N; 70° 30'E), Taunsa (30° 42'N; 70° 37'E) and Bakkur (31° 37'N; 70° 07'E). The geological setting explains the high thermal activity in this region (see Chapter 2.23).

The South Sulaiman geothermal zone covers the area of maximum thickness and deepest burial of the sedimentary pile (over 15 km) (Fig. 7.22; Raza et al. 1990). This zone is seismically active and a number of earthquakes with magnitudes 3 to 7 on the Richter scale have been recorded (Kazmi 1979 b). To the south it is intersected by the Mari-Khandkot horst which is probably flanked by deep seated faults. Its

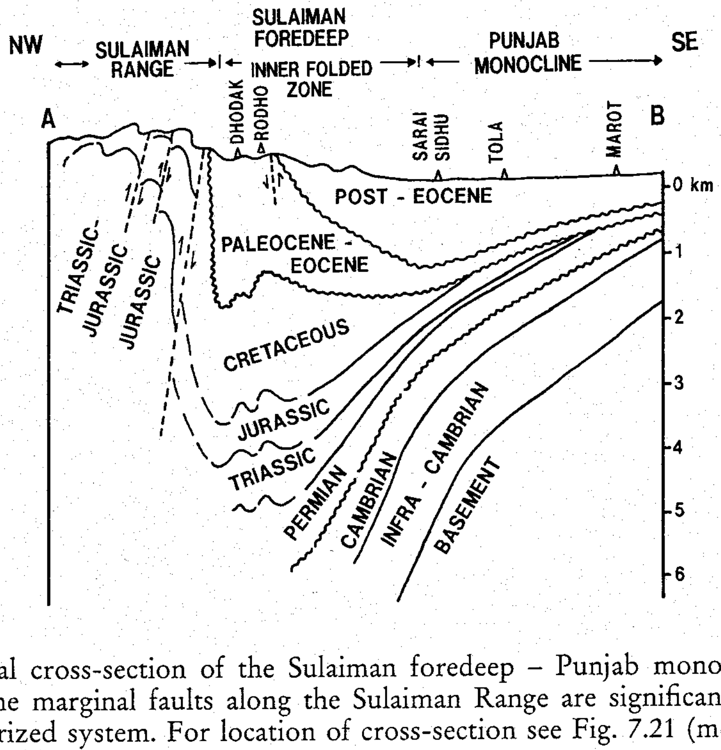


Fig. 7.22. Geological cross-section of the Sulaiman foredeep – Punjab monocline. The thick pile of sediments and the marginal faults along the Sulaiman Range are significant components of the Sulaiman geopressurized system. For location of cross-section see Fig. 7.21 (modified after Raza et al. 1989).

western margin is deformed by a number of faults. Many lineaments have been traced on the surface which probably are reflections of basement faults (KAZMI 1979). In the subsurface, the Khadro Formation, which consists of basalt and shale, forms an impervious layer at the base of the Palaeogene, causing hydrostatic pressure and insolation for upward heat flow. The great thickness of sediments and depth of burial has generated exceptionally high geothermal temperatures in depth. It appears likely that thermal water is leaking through a fault, fracture or fissure at Giandari, giving the impression of the presence of a "warm spot" beneath Giandari.

Recent interpretation of seismic data from the south Suleiman region by JADOON (1991) reveals a passive-roof duplex structure bounded by a roof thrust in Cretaceous shales, and a floor thrust in the Palaeozoic section at the base of the wedge (Fig. 7.23). This structural feature to some extent explains the enhanced geothermal gradient in this region.

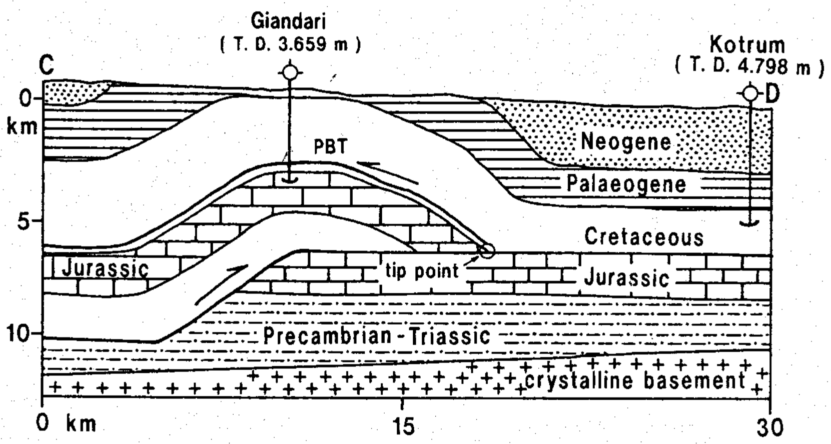


Fig. 7.23. Structural cross-section of a part of the south Sulaiman geothermal zone. PBT = passive backthrust. Location of cross-section shown in Fig. 7.21 (after JADOON 1991).

The gas field near Khairpur contains more than 70 per cent carbon dioxide. According to ABID (1975), CO_2 may have formed as a result of the break down of limestone by intrusions of igneous rocks in the sub-surface. Seismic surveys reveal deep faults along which CO_2 and thermally active water may have escaped to form the sulphur deposits near Khairpur and Shikarpur.

The **South Kirthar geothermal zone** comprises the southern part of the Kachhi (or Kirthar) Foredeep (KAZMI & RANA 1982), which is also referred to as Kirthar Depression (RAZA et al. 1990). It includes the Sanbakh saddle and Lakhra arch (southeastern components of the Kirthar fold belt; KAZMI & RANA 1982). In this zone hot springs are present at Lakhi (26° 16'N; 67° 55'E). The temperature of the springs is about 46 °C. Near Sehwan (26° 23'N; 67° 54'E) there are a number of highly sulphurous springs. OLDHAM (1882) and BAKR (1965) have recorded hot springs in this zone at the following localities:

Jein – Pir	25° 00'N; 68° 03'E
Tong	25° 46'N; 67° 36'E
Pokran	25° 48'N; 67° 48'E
Rani-Jo-Kot	26° 07'N; 67° 58'E
Khosra-ke-Wahi	26° 08'N; 67° 48' 30"E
Garm Ab	26° 13'N; 67° 42'E
Khai	26° 15'N; 67° 42'E
Kandhar	26° 14'N; 67° 35'E
Pir Ari	26° 18"N; 67° 47'E
Naing	26° 19'N; 67° 32'E
Phadak	26° 25'N; 67° 33'E
Gorandi	26° 26'N 30"; 67° 32'E
Ghazipir	26° 27'N; 67° 30'E
Tando Rahim Khan	26° 30'N; 67° 30'E
Wahi-Pandi	26° 41'N; 67° 16'E.

Oil and gas wells drilled at Lakhra show thermal gradients above normal (3.3 °C/100 m). One of the wells drilled to 3,800 m encountered water at high pressure and temperature (160 °C) from a permeable horizon (ABID 1975). Farther southward the oil and gas wells at Sari and Karachi revealed a geothermal gradient of about 3 °C/100 m. Near Karachi hot springs are located at two localities and these have been studied in some detail by the Geological Survey of Pakistan (TODAKA et al. 1988). Two of these are located at Mangho Pir (24° 59'N; 68° 03'E) and one at Karsaz (24° 53'N; 67° 06'E). Some of the physical and chemical characteristics of these springs are shown in Table 7.8. TODAKA et al. (1988) mentioned that the structural and other conditions at Karachi are similar to those at the Kizildare (Kizildagh) geothermal field in Turkey. However, they

Table 7.8. Physical and chemical characteristics of the Manghopir and Karsaz thermal springs (after TODAKA et al. 1988).

locality	Manghopir	Karsaz
aquifer	Nari Formation	Gaj Formation
temperature	50.3 °C	39.0 °C
pH	7.45	7.87
EC (mohs)	2.380	7.910
gas	CO_2 bubbling	CO_2 bubbling
ion charge balance	2.2 %	3.8 %
spring type	$Cl\text{-}HCO_3$	$Cl\text{-}SO_4$
Ca (mg/l)	56	1,971
Na (mg/l)	355	1,400
K (mg/l)	14	81
Mg (mg/l)	34	124
SiO_2 (mg/l)	24	46
reservoir temperature		
by SiO_2 geothermometer	71 °C	89 °C
Na-K-Ca geothermometer	138 °C	170 °C

suggest that the silica geothermometer probably indicates lower reservoir temperature in the Karachi area, i.e. less than 100 °C, because the silica content is low and there is a possibility of sea water influence.

The geological setting of the South Kirthar geothermal zone is similar to that of the South Sulaiman geothermal zone. The Kirthar zone also includes a depression containing a pile of sediments 6 km–10 km thick. The eastern part of this pile forms a wedge and some of it is exposed in India, forming an effective recharge zone. The western margin of this thick sedimentary prism is deformed by tight folds and faults, notably the Kirthar fault (KAZMI & RANA 1982). Lineament traces suggest the presence of deep basement faults. The region is seismically active and epicenters of shallow earthquakes ranging in magnitude from 3 to 7 on Richter scale have been recorded. A few major faults in this region, such as the Kirthar fault, the Surjan fault and the Jhimpir fault (KAZMI 1979 a, 1979 b 1982), are believed to be active and some of the hot springs are located in their proximity.

The **Lower Indus trough and the offshore geothermal zone** is characterized by geothermal gradients above normal, which were encountered in some oil and gas wells (KAZMI & RANA 1982). The well Damiri-1 had a geothermal gradient of 4 °C/100 m (KHAN & RAZA 1986), whereas the wells at Talhar and Khaskheli have encountered geothermal gradients in the range of 3 ° to 3.5 °C/100 m. The offshore well at Dabbo Creek revealed a geothermal gradient of 3.7 °/100 m. The southern part of the Lower Indus trough forms a monocline containing a prism of sediments ranging in age from Triassic (and older) to the Neogene. There is a marked unconformity at the base of the Palaeogene. In the areas with higher geothermal gradients the Mesozoic rocks are capped with volcanics of the Deccan trap. This feature partly accounts for the higher geothermal gradient. The strata below the trap are traversed by several deep-seated faults, which apparently do not affect the Cenozoic strata. Some of these faults may be the avenues for thermal water.

In other parts of the **Indus and Baluchistan sedimentary basins**, geothermal manifestations in the form of hot springs are scattered, associated mainly with seismotectonic and suture zones (BAKR 1965; ABID 1975). Three hot springs are located in the foothill region of the Kirthar Range west of Dhadar, near Sanni, and south of Thal (Fig. 7.21). They appear along the Mach and Kirthar faults (KAZMI 1979 a; 1979 b) at the western edge of the Kirthar Foredeep which has a pile of sediments more than 10 km thick. This is a region of high seismicity also (KAZMI 1979 b; QUITTMEYER et al. 1979). Though the oil and gas wells drilled in the Kirthar Foredeep, not far from these springs, do not show unusually high thermal gradients, it is likely that in the eastern part of the Kirthar fold belt the geothermal gradient has increased substantially accompanied by seismotectonic activity along the Kirthar foothills.

Hot springs are present in many parts of Baluchistan, associated with faults and seismic activity. In the Harnai Valley area, according to BAKR (1965), thermal springs of importance are located in the hill ranges north and north-northeast of the Spintangi railway station. These springs are apparently associated with the Harnai and Tatra faults (KAZMI 1979 a). Seismically this is a very active region (KAZMI 1979 b; QUITTMEYER 1979). Earthquakes of magnitudes 6 to over 7 on Richter scale have been recorded. Higher than normal geothermal gradients may be expected in depth in the Harnai-Spintangi region. Two hot springs are located north of the Zhob Valley (Fig. 7.22; ABID

1975). They apparently occur amidst a series of imbricated faults (BAKR 1965; KAZMI 1979b) in a region of relatively high seismicity. In the Baluchistan Basin, ABID (1975) has shown a number of hot springs north of Santsar, near Diz and southeast of Garruk. These hot springs are also near major faults, particularly the one near Garruk which is located in an area of high seismicity.

A hot spring is present in North Waziristan (ABID 1975) in the foreland thrust belt in a region that is geologically not yet adequately explored. BAKR (1965) described a number of thermal springs with temperatures ranging from 85 ° to 90 °F in the Nammal Gorge area of the Salt Range. Thermal springs also occur in the foothill area of the Salt Range, the Potwar Plateau, the Margalla Hills and in Azad Kashmir (Fig. 7.21). All of these are apparently located close to faults or lineaments and are probably related to seismotectonic activity.

7.52 Seismotectonic and suture related systems

Geothermal regimes in the northern part of Pakistan, as indicated by many thermal springs, are associated with sutures and related structures in one of the most seismically-active parts of the country (see Chapters 2.25, 5.25).

Thermal springs within the Reshun and Ayun fault domain are located at Garm Chasma (meaning hot spring) about 50 km northwest of Chitral (Fig. 7.21). These springs are near the contact of granites intruded in metasediments, within 27 km of the Reshun fault (CALKINS et al. 1981), in a region of extremely high seismicity. Another hot spring (36° 45'N; 73° 15'E) is reported near the snout of Pechus glacier, about 105 km northeast of Mastuj (BAKR 1965). It is located near the contact of granite intruded in Cretaceous metasediments, close to the Reshun fault (CALKIN et al. 1981). In Yasin District, a hot sulphurous spring is located 3 km north of Rawat Village (36° 43'N; 73° 22'E). It emanates from the metasediments of the Darkot Group close to the Ayun fault (CALKIN et al. 1981, BAKR 1965).

Further thermal springs are related to the geothermal system of the Main Karakorum Thrust (MKT) in the western part of the Hunza Valley. One cluster of five springs is near Murtazabad Village, whereas three closely-spaced hot springs flow into the Bola Das River within 15 km of Budelas Village. These springs have been studied in some detail by TODAK et al. (1988). The springs near Budelas emanate from the Baltit Group of metasediments, within 6 km to 17 km of the MKT, along a north-south trending lineament. A short distance to the north, the Karakorum granodiorite intruded the Baltit Group sequences. The spring nearest to the granodiorite has a temperature of 91 °C. Those farther away to the south have a temperature of 35 °C only. TODAKA et al. (1988) believed that this geothermal system is based on the hot springs generated by friction along the MKT; however, the heat may be caused by radio-active decay of the Karakorum granodiorite. Based on geochemical studies these authors estimated the temperature of the Budelas reservoir to range from 172 ° to 189 °C.

The Murtazabad hot springs are situated within 7 km of the MKT; their water temperature ranges from about 26 ° to 91 °C (SHUJA & SHEIKH 1983). The reservoir temperature at this site has been estimated to range from 198 ° to 212 °C.

There are two thermal springs south of the MKT near Jaglot with water temperature ranging from 50 ° to 65 °C (SHUJA & SEIKH 1983). At this point the reservoir temperature has been estimated to range from 85 ° to 160 °C.

Farther to the southeast, in the Skardu District, two sulphur springs and three hot springs have been reported in the Dassu area. The maximum water temperature of these springs is 71 °C. They are also located in the vicinity of the MKT, close to granitic rocks and are apparently linked with NW-SE and NE-SW trending fractures and lineaments. According to TODAKA et al. (1988), the geological conditions in the Dassu area are similar to those of Murtazabad and Budelas.

The geothermal system related to the Nanga Parbat – Haramosh Massif (see Chapter 2.25) forms hot springs along the faulted margins of the massif. On the eastern side there is a hot spring near Dasakin in the Astore Valley. It is close to the Main Mantle Thrust (MMT), the water temperature is about 57 °C. The estimated reservoir temperatures (silica geothermometer) range from 86 ° to 90 °C (TODAKA et al. 1988).

Hot springs emanate from the Raikot fault zone along the western margin of the Nanga Parbat – Haramosh Massif at Sassi and at Tatta Pani, along the Indus. The Sassi spring has a field temperature of 54 °C, whereas the reservoir temperatures range from 40 ° to 48 °C to 152 °C (TODAKA et al. 1988).

There are a number of hot water springs in the Tatta Pani area, arranged in a row on either side of the Rakhiot bridge and spread over a distance of about 8 km. They emanate from Quaternary terraces and colluvial deposits. In the vicinity of these springs (5 km north of Rakhiot bridge), the bed rock is thrust over Holocene gravels (LAWRENCE & GHAURI 1983). The water temperature of the springs decreases westward from 83 ° to 65 °C. Reservoir temperatures (silica geothermometer) range from 51 ° to 91 °C and by Na-K geothermometer they range from 93 ° to 128 °C. TODAKA et al. (1988) indicate reservoir temperatures to be 90 ° to 110 °C, which is consistent with the temperature defined by the Na-K geothermometer.

7.53 Systems related to Neogene-Quaternary volcanism

Geothermal systems associated with the Chagai magmatic arc (see Chapter 5.23) are manifested by mineralized warm water springs which are largely confined to the Koh-i-Sultan and appear in the vicinity of the Miri crater (Fig. 7.24). The water temperatures of the springs, which range from 25.6 ° to 32 °C, are lower than the ambient temperature in summer season. An acidic alteration zone has formed southwest of the Miri peak. A part of this zone is strongly silicified. Hydrogen sulphide was observed in places and there are scattered sulphur deposits in the alteration zone. A preliminary geothermal study of this region has been done by the Geological Survey of Pakistan and the relevant information is shown in Table 7.9.

In the Koh-i-Sultan geothermal system, the reservoir temperatures estimated on the basis of the silica geothermometer range from 150 °C to 175 °C (SHUJA et al. 1984). This region apparently has the highest geothermal potential in Pakistan and an economically exploitable geothermal reservoir may be expected in the southwestern part of Koh-i-Sultan.

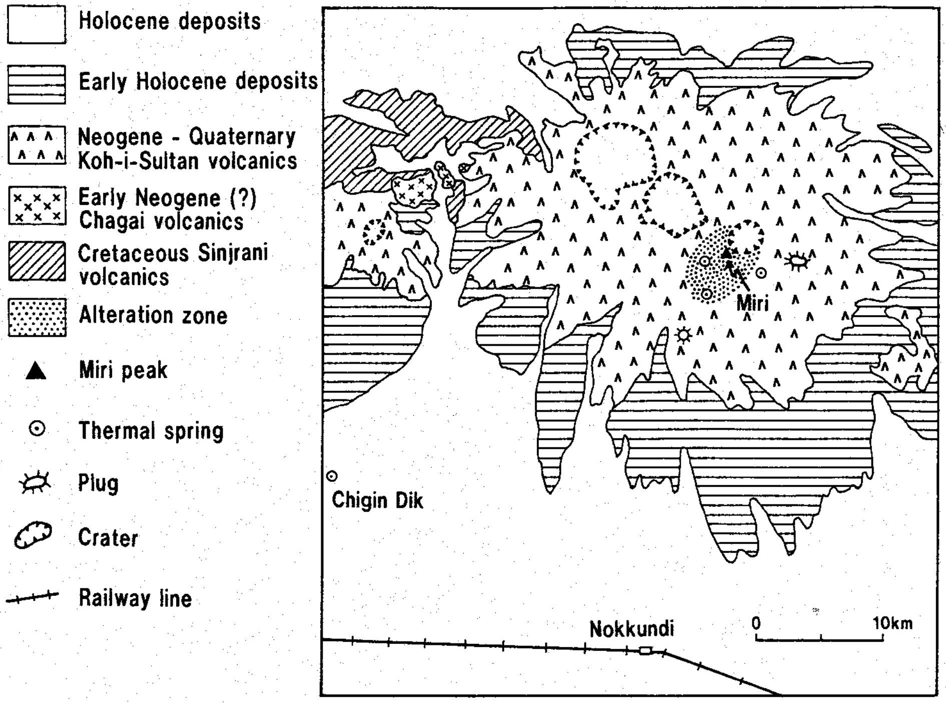


Fig. 7.24. Geological sketch map of the Koh-i-Sultan volcanogenic geothermal zone.

Table 7.9. Physical and chemical characteristics of thermal springs of Koh-i-Sultan area (after TODAKA et al. 1988).

Location	Chigen Dik	east of Miri	WSW of Miri	southwest of Miri
temperature (°C)	29.9	29.5 – 30.2	26.9	25.6
pH	6.58	7.44 – 6.89	2.77	2
EC (mohs)	> 10,000	> 10,000	> 10,000	–
surface rock	Holocene deposits	agglomerates	andesite	andesite
flow (l/min)	–	< 1	< 1	negligible
other features	geyser	discharge from river bed	sulphur and salt encrustation	sulphur and salt encrustation
TSM (mg/l)	28,920	13,700 to 18,780	67,540	18,440
Na (mg/l)	8,625	3,125 to 5,500	2,475	4,325
K (mg/l)	170	370 to 800	65	2,180
Ca (mg/l)	136	344	1,543	577

Table 7.9. Continued.

Location	Chigen Dik	east of Miri	WSW of Miri	southwest of Miri
Mg (mg/l)	457	374 to 452	1,410	345
Cl (mg/l)	10,354	4,858 to 6,205	7,056	7,801
SO_4 (mg/l)	5,310	2,292 to 3,036	42,585	2,325
HCO_3 (mg/l)	2,985	1,038 to 2,044	0	713
SiO_2 (mg/l)	69	27 to 55	188	73

8. Metallic raw materials

(FAIZ AHMAD SHAMS)

Prior to the partition of (British) India in 1947, the territory that constituted Pakistan was considered almost barren as far as metallic raw materials were concerned (see, for example, the compilation by LA TOUCHE 1917). Even the first-ever publication on mineral deposits of Pakistan (HERON 1950) mentioned only nine metals (As, Au, Be, Cr, Fe, Cu, Mn, Pb, Sb), many of which were termed "trivial". Post-independence reconnaissance geological surveys and prospecting, however, yielded mineral discoveries in quick succession that justified a comprehensive publication by the Geological Survey of Pakistan (ZAKI 1969). Localities of metallic and non-metallic raw materials, hydrocarbons and coal are shown on Fig. 8.1 (locality map, fold-out).

Table to Fig. 8.1: Locality map of metallic and non-metallic raw materials, hydrocarbons and coal (compiled by F. BENDER).

No.	Name	Minerals	Lat.°	Long.°
1	Makhad	Au	33.13	71.80
2	Drosh	Au,Cu,Mic.	35.57	71.80
3	Arandu	Au	35.87	75.33
4	Reshun	Au	36.18	72.12
5	Tarbela	Au	35.28	75.65
6	Darwazai	Au	33.83	72.23
7	Kirana	Au,Fe	29.14	71.34
8	Averit	Au,Ag,Pb,Sb	36.00	71.50
9	Hal	Au,Ag,Pb	34.13	73.20
10	Ushu	Ag,Pb,Zn	35.53	74.67
11	Loe Shilman	Nb,Ta,REE,U	34.23	71.16
12	Bela	Pt,PtM,Cr	26.15	66.17
13	Jijal	Pt,Te,Fe,Cr	34.97	72.00
14	Dasht-e-Kain	Cu	29.55	64.48
15	Amir Chah	Cu	29.02	62.63
16	Dalbandin	Cu	28.87	64.40
17	Koh Marani	Cu	29.58	66.50
18	Ziarat	Cu,Sb,Gls.	30.17	67.42
19	Fort Sandeman	Cu,Cr,Mn	31.35	69.48
20	Datta Khel	Ci	32.53	69.32
21	Dammal Nissa	Cu,Pyr.,Fe	35.22	71.40
22	Yarkun	Cu	36.58	72.88
23	Haripur	Cu	33.98	72.92

No.	Name	Minerals	Lat.°	Long.°
24	Besham	Cu,Pb,Zn,Mo,Co,Sn,Bi,Cd	34.56	72.52
25	Kalam	Pb,Zn	35.57	72.72
26	Pakhturi	Pb,Zn,Sb,Cu	36.37	72.30
27	Dirang Kalat	Pb,Zn	29.47	64.55
28	Gunga	Pb,Zn,Ag,Sb,Ba	27.73	66.58
29	Duddar	Pb,Zn,Ag,Sb,Ba	26.10	66.83
30	Chilgazi	Fe,Au,Ag	29.13	64.23
31	Mashki Chah	Fe	28.03	64.40
32	Kundi-Baluchap	Fe	29.13	64.50
33	Kharwala Nala	Fe	33.93	70.01
34	Shekran	Fe	27.85	66.38
35	Pezu	Fe,Gls.	32.29	70.44
36	Rakhi Munh	Fe	29.95	70.12
37	Kolai	Fe	34.57	73.02
38	Mazari Tang	Fe	33.75	71.92
39	Kalabagh	Fe,C,U	32.92	71.53
40	Langrial	Fe	33.93	73.12
41	Sonaro	Cr	26.36	66.48
42	Muslimbagh	Cr	30.51	67.40
43	Chilas	Cr	35.43	74.07
44	Gadani	Mn	25.10	66.70
45	Mohammad Khan Bent	Mn	26.52	66.40
46	Kharrari Nai	Mn	25.90	66.75
47	Khan Kheo Nai	Mn	26.18	66.57
48	Sanjro	Mn	26.47	66.45
49	Galdanian	Mn	36.27	73.32
50	Chur Gali	Mn	34.3	73.47
51	Thal	Mn,Sb	33.37	70.58
52	Fort Saindak	Cu,Mo	29.17	61.34
53	Panjia	Cu,Mo,Ky	34.52	73.02
54	Oghi	Cu,W,Ky	34.20	74.32
55	Amalaf	W	29.30	61.62
56	Souch	Ni	34.92	73.67
57	Garhi Habibullah Khan	Al	34.40	73.40
58	Muzaffarabad	Al	34.35	73.50
59	Kotli	Al	33.52	73.90
60	Kamroti	Al	33.60	74.07
61	Krinj	Sb	36.05	71.46
62	Qila Abdullah	Sb	30.44	66.40
63	Mirgasht	As	36.43	72.29
64	Rajdhawari	Fsp.,Qu.,U	34.00	73.11
65	Sakhakot	REE	34.40	71.93
66	Bagh Fort	Ab	34.12	71.12
67	Boya Scout Post	Ab	32.96	69.93
68	Kaniguram	Ab	32.52	69.85
69	Nako Pabni	Ba	26.77	66.52
70	Khuzdar	Ba,F	27.78	66.58
71	Daud Khel	Sr	32.56	71.36
72	Dazu	Fsp.,Mic.	35.18	73.20
73	Dilband	F	29.53	66.92
74	Koh-i-Maran	F	29.42	66.50
75	Paniala	Gls.	32.23	70.90

No.	Name	Minerals	Lat.°	Long.°
76	Manda Kachcha	Gls.	34.67	73.27
77	Jungshahi	Gls.	24.87	67.17
78	Shahid Mena	Gra.	34.15	71.28
79	Chalt	Gra.,Tal.	36.16	74.18
80	Skeikh Wasil	Gra.	29.92	66.60
81	Neelam River	Gra.	34.94	74.22
82	Dera Ghazi Khan	U,Mo,Gyp.	30.04	70.38
83	Daud Khel	Gyp.	32.53	71.49
84	Saidu Wali	Gyp.	34.75	72.17
85	Chamalang	Gyp.	30.20	69.42
86	Spin Tangi	Gyp.,Mag.	29.55	68.05
87	Khewra	Gyp.,PS,RS	32.65	71.75
88	Kuz Banda	Ky	34.63	73.00
89	Landakai	Ky	34.65	72.13
90	Sherwan	Mag.	34.12	73.04
91	Shabi Ghundi	Mag.	30.80	68.17
92	Baltit	Mic.,As	36.26	74.42
93	Kutki	MP	32.98	71.35
94	Pirkahar	MP	32.65	72.72
95	Jhol Dhand	MP	24.87	67.93
96	Sonhari Dhand	MP	25.00	68.07
97	Kalkul	P	34.20	73.28
98	Normal	Pyr.	36.15	74.25
99	Dainyor Nala	Pyr.	36.02	74.25
100	Khaiber	Qu.	36.57	74.80
101	Morkhun	Qu.	36.62	74.87
102	Iskhere	Qu.	35.78	74.80
103	Jotial	Qu.	35.72	74.95
104	Chitta Batta	Qu.	34.37	73.27
105	Sanni	S	29.03	67.49
106	Koh-i-Sultan	S	29.12	62.78
107	Kund	Tal.	33.93	72.23
108	Bhimber	Ben.	32.97	74.08
109	Jammu	Ben.	32.44	74.10
110	Qadirpur	Ben.	29.36	72.05
111	Bhadrah	Ben.	27.20	68.01
112	Ahl	Cly.,U	34.57	73.15
113	Shah Dheri	Cly.	34.88	72.90
114	Battal	Cly.	34.59	73.13
115	Nok Kundi	Mar.	28.81	62.09
116	Maneri	Mar.	34.13	72.47
117	Saidu Sharif	Mar.	34.89	72.90
118	Karora	Mar.	34.51	72.46
119	Jarl	Dol.	34.15	73.08
120	Sobran Gali	Dol.	34.17	73.15
121	Warcha	RS	32.48	71.98
122	Hamun-i-Mashkel	RS	28.30	62.75
123	Khaltaro	GeE	35.96	74.69
124	Dandao Kandao	GeE	34.46	71.54
125	Arang Barang	GeE	34.61	71.57
126	Mingora	GeE	34.78	72.37
127	Gujarkili	GeE	34.78	72.63
128	Timargarah	GeR	34.86	71.88

No.	Name	Minerals	Lat.°	Long.°
129	Kabal	GeR	34.77	72.28
130	Ishkoman	GeR	36.33	73.48
131	Kundal	O	32.53	71.30
132	Khattan	O	29.57	68.47
133	Khaur	O	33.25	72.45
134	Dhulian	O	33.20	72.35
135	Joya Mair	O	32.98	72.77
136	Balkassar	O	32.94	72.66
137	Sui	G	28.64	69.21
138	Zin	G	28.94	68.73
139	Uch	G	28.64	68.62
140	Khairpur	G	27.50	68.78
141	Mari	G	27.94	69.76
142	Kandhkot	G	28.18	69.22
143	Mazarani	G	27.68	67.51
144	Toot	O	33.13	72.04
145	Meyal	O	33.30	72.17
146	Khaskeli	O	24.81	68.57
147	Adhi	O+G	33.13	73.15
148	Dakhni	G	33.42	71.95
149	Dhurnal	O	33.34	72.59
150	Chak Naurang	O	32.99	72.93
151	Dhodak	G	30.87	70.38
152	Pirkoh	G	29.14	69.09
153	Rhodo	G	30.74	70.44
154	Loti	G	28.94	69.07
155	Panjpir	G	30.68	71.96
156	Nandpur	G	30.53	71.93
157	Sari Sing	G	25.22	67.54
158	Hundi	G	25.20	67.70
159	Burikhel	C	32.68	71.63
160	Makarwal	C	32.52	71.71
161	Karak	C	33.10	71.07
162	Hangu	C	33.52	71.05
163	Bahlol	C	30.02	69.47
164	Kalabagh	C	32.97	71.57
165	Mach	C	29.87	67.85
166	Khost	C	29.20	67.08
167	Sharigh	C	30.23	67.72
168	Harnai	C	30.10	67.90
169	Duki	C	30.15	68.57
170	Chachro	C	25.67	70.25
171	Badin	C	24.67	68.83
172	Lakhra-Sonda	C	24.98	68.13
173	Thatta	C	24.75	67.92
174	Meting	C	25.17	68.12
175	Tando Mohammad Khan	C	25.13	68.53
176	Jhimpir	C	25.02	68.02
177	Darband	C	34.30	72.87
178	Bunji	U	34.67	74.65
179	Dargai	U	34.47	71.90

8.1 Metallogeny

The first attempt for a regional metallogenic explanation was made by SHCHEGLOV (1969) who concentrated on endogenous metallogeny of southern Pakistan and distinguished three "ore-belts":

- The chromite ore-belt, characterised by Cretaceous-Palaeogene ultramafic rock masses, carbonate complexes and submarine volcanics. This belt extends from Karachi to Muslimbagh to Waziristan and contains Cr, Mn, Pb;
- the mercury-antimony ore-belt, developed in the late stage of the Oligocene "geosynclinal trough" of the Pishin-Makran region;
- and the copper-molybdenum ore-belt, developed in the Chagai median massif with acid complexes of post-Oligocene age containing Cu, Fe, Mo.

Following the advent of the theory of plate tectonics, SILLITOE (1975, 1978) reinterpreted the metallogenic evolution of southern Pakistan and defined five post-Paleozoic environments:

- Continental shelf of the Indo-Pakistan Plate; carrying stratabound Mississippi-Valley type fluorite-barite deposits, with Pb in the Bela-Khuzdar region and Pb, Fe in the Shekran District, hosted by Jurassic limestones;
- calc-alkaline magmatic arc belt, carrying Cu, Mo, Pb related to Middle Miocene tonalite porphyries at Saindak; manto-type Cu at Amuri and Talaruk related to Cretaceous submarine Sinjrani Volcanics; contact metasomatic Fe, Cu ores in Cretaceous limestone at Kundi-Baluchap and at Mashki Chah; volcanogenic Fe, Cu of Cretaceous age at Chilgazi, Pachin Koh;
- ophiolite suture zone, containing Cr in ultramafite complexes extending from Las Bela to Muslimbagh to Waziristan, stratabound Mn ore related to basalts at Kharrari and Siro Dhoro; stratiform massive Cu sulphide at Ann Dhora related to "Layer-2 Basalts", all generated at the oceanic ridge of Mesozoic age;
- Chaman transform fault zone, carrying Sb, Hg in the Oligo-Miocene flysch at Qila Abdullah;
- molassic basins of the Siwalik system, carrying U and V in clastics shed by the rising Himalayan orogen.

Later, SILLITOE (1979) extended the plate tectonic classification of metallogeny to northern Pakistan, concentrating on the Himalayan region and contiguous areas. He treated known mineralizations on a two-fold subdivision, i. e. metamorphic deposits, and mineralization related to anatectic granites, and stressed the importance of pre-Mesozoic mineralization involved in the Himalayan orogeny. More recently, plate tectonic treatment of metallogeny has been attempted either for specific regions, or for specific metals. For example, TAHIRKHELI (1979) discussed the main subduction zone between Indo-Pakistan and Eurasian Plates in northern Pakistan, listing metals related to:

- the subducted rocks of the marginal Indo-Pakistan Shield with Pb, Sb, Cu, Fe, U, Be, Ti, Ta, Cd, rare earth elements (REE);

- the Volcanic Island Arc Complex (Kohistan-Deosai Zone) with Cu, Pb, Mo, Mg, U, Sb, Mn;
- Peridotite complexes (ophiolite complexes) with Cr, Fe, Ni, Mg.

SHAMS (1983) concentrated on metallogeny of uranium in relation to plate tectonic evolution of northern Pakistan, and gave a treatment on the basis of:

- remobilized Cambrian granites: Mansehra, Lahor, Swat granites;
- syenite-nepheline syenite complexes: Peshawar Depression alkaline complexes;
- Karakorum-eastern Hindu Kush region: pegmatites;
- sediments of the River Indus: placers.

Individual mineral occurrences and localized mineralized zones have been discussed also by many workers. A relatively comprehensive plate tectonic treatment of metallogeny in Pakistan was offered by AHMAD & GAUHAR (1986). Forwarding a concept of "metallotect zonation", these authors presented a classificatory treatment and defined six post-Paleozoic environments as follows:

- subduction zone: Chagai (Cu, Mo, Fe, Au), Ras Koh (Fe, Cu, Cr), Khojak (Sb);
- collisional zone: Kohistan (Fe, Pb, Zn, Cu, Mo), Karakorum (Be), crystallines (Sb, Be), alkaline complexes of Peshawar Valley, (U, REE);
- obduction zone: ophiolites (Cr, Fe, Cu, Mn);
- transform boundary: Chaman Fault (Sb);
- pre-collisional margin platform zone: shelf carbonates (Pb, Zn);
- Indo-Pakistan Plate region: Siwalik molasse (U), Salt Range (Fe); Shield elements: (Fe, Au).

SCHRÖDER (1984) attempted a correlation of metallogenic and tectonic zones between Afghanistan and Pakistan, from Karakorum and Wakhan in the northwest and Chagai Hills in the southwest.

8.2 Noble metals, niobium, tantalum, tellurium

Gold as primary mineralization is observed in a wide range of host rocks from the Chagai District to the Northern Areas. There are also extensive occurrences of placer gold at many localities in the Indus River Basin.

Placer gold-washing has been practised in northern Pakistan even earlier than the time of the invasion of Alexander the Great. Main gold-washing localities are spread along the Indus River, and its tributaries in Baltistan, Gilgit and Diamir Districts, along the Chitral River in the North-West Frontier Province (N W F P), and in the Province of Punjab (HERON 1954, ZAKI 1969). Gold-washing along the Indus River has been carried out between Attock and Kalabagh in the Punjab Province; particulary important has been the Makhad (33° 08'N; 71° 48'E) location. Gold-washing is reported also from Soan River, and from Bunha and Kahan tributaries of Jhelum River, in the District Jhelum, Punjab Province (HERON 1954).

Gold-washing has been practised in the Chitral District, N W F P, mainly from the Chitral River between Drosh (35° 34'N; 71° 48'E) and Arandu (35° 52'N; 75° 20'E), and from Reshun (36° 10'N; 72° 07'E) River and other tributaries that rise from the Phargam Mountains composed of granitic gneisses (HERON 1954). Other gold-washing localities in N W F P are Tarbela (34° 77'N; 74° 99'E), Lalogali (13° 16'N; 72° 51'E), Kirpalian (34° 17'N; 72° 51'E), Banda Zartangi (33° 17'N; 71° 32'E), Kalapani S of Mardan (34° 12'N; 72° 03'E) and Darwazai (33° 50'N; 72° 14'E).

Many reconnaissance surveys were carried out for gold (DANILCHIK et al. 1959, TAHIRKHELI 1960). Austromineral (1976) surveyed a large part of the Northern Areas, and showed that gold content within the river gravel reserves of 250 million m^3, were about 615 kg. No source rock of primary gold could be located although small nuggets were recovered occasionally from the Shimshal (36° 27'N; 75° 20'E) River bed, upper Hunza. The claims have not been investigated so far that gold-bearing pyrite occurs in limestone near Charbagh Fort (34° 07'N; 71° 07'E) in Khyber Agency, and as sparse disseminations in acid volcanics north of Injan Dheri (34° 14'N; 72° 17'E) in Mardan District (HERON 1954).

Primary gold, as much as 6 ppm, has been reported from diabase intrusives in the Precambrian shield outliers of Kirana (31° 58'N; 72° 34'E), District Sargodha, Punjab Province (SHAH 1973). Notable, however, is the boulangerite from near Averit (Awerith) (36° 00' 00"N; 71° 30' 00"E) stibnite area of Chitral, N W F P (Fig. 8.2), which showed gold contents from 30 ppm to 60 ppm (REHMAN 1975, CALKINS et al. 1981). Many pods as much as 0.7 m thick are present along the northeastern faulted contact of the Shogor Limestone. Recently, a carbonate mineralized layer 8 m to 70 m thick was located southwest of Averit. The grade is as much as 70 g Au/t, and averages 5 g Au/t, for 8 million t of outcrop material between Drunil and Averit (DAMES & MOORE 1987). Gold associated with galena is recorded from Hal, west of Abbottabad (34° 08'N; 73° 12'E), N W F P, where the sulphide ore carries traces to 0.00017 % of Au (SHAMS 1963).

The Saindak copper porphyry deposits in the Chagai District, Baluchistan Province, are the largest gold-bearing sulphide prospects identified so far; about 599 t of gold has been estimated to be present in the 412 million t of mineralized rock (SHEIKH 1979). Other gold-bearing sulphide localities are also known from the Chagai District (SCHMIDT 1968, ZAKI 1975).

Silver is found in association with certain sulphides, such as the auriferous boulangerite from Averit (36° 00' 00"N; 71° 30' 00"E), which contains as much as 1.200 ppm of Ag (Fig. 8.2; CALKINS et al. 1981). The auriferous carbonate mineralized zone, southwest of Averit, has been found to contain Ag in the range of 10 to 15 g/t (DAMES & MOORE 1986). Galena and sphalerite of Ushu (35° 32'N; 74° 40'E), District Swat , N W F P, contain on average 834 ppm and 127 ppm Ag, respectively, along with Au, Sb, and Cu (RAHMAN 1978, TAHIRKHELI 1960). The galena of Hal, NW of Abbottabad (34° 08'N; 73° 12'E), N W F P, shows 0.017 % of Ag (SHAMS 1963).

The Saindak porphyry copper bodies contain about 635 t Ag as pyrargyrite (SHEIKH 1979), recoverable as by-product of copper processing.

Ag is not a significant constituent in gold placers of northern Pakistan; analyses show 0.0003 % Ag in Indus River sands at Darband (26° 20'N; 62° 39'E), 0.0007 % Ag in the Hunza River sands at Baltit (36° 20'N; 74° 31'E; DANILCHIK et al. 1959).

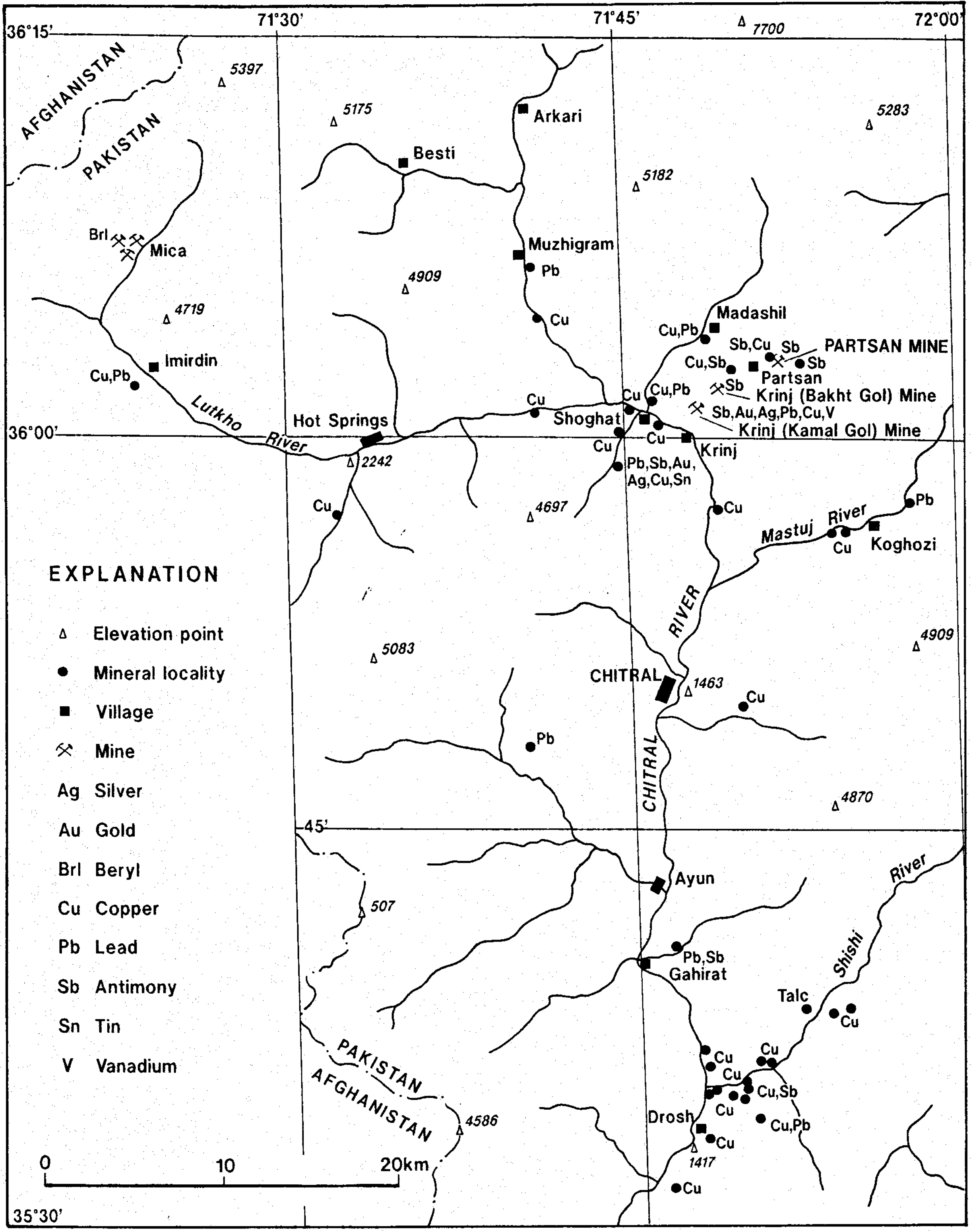


Fig. 8.2. Mineral localities in the Chitral-Partsan area, northern Pakistan (after CALKINS et al. 1981, fig.3).

A heavy mineral concentrate from the Indus River near Attock (33° 46'N; 72° 21'E) showed 8.51 g Ag/t (MILLER 1962).

Niobium and tantalum are known from dykes, sills and rings of carbonatites in alkaline complexes (see Chapter 4) in the N W F P near Loe Shilman (34° 13' 32"N; 70° 09' 25"E), Khyber Agency. They are intrusive in Precambrian schists, and contain 0.01 % to 0.03 % Nb (ASHRAF et al. 1977), with pyrochlor (22.0 % Nb; 7.0 % Ta), and betafite (21.4 % Nb; 6.40 % Ta), as the specific ore minerals (SYED 1975, RAHMAN 1980, BUTT et al. 1981). Other carbonatite bodies within the alkaline complexes of the N W F P have not been tested yet although the presence of rare earth elements (REE) is known (SIDDIQUI 1967, KHATTAK et al. 1984, BUTT et al. 1989).

Tellurium is known from a recent discovery in the ultramafic and noritic gabbros of the Jijal (34° 58' 00"N; 72° 00' 18"E) obducted block, District Kohistan, N W F P, and in layers of the Chilas mafic-ultramafic complex, District Diamir, Northern Areas, where it is present as palladium telluride (ASHRAF 1990).

8.3 Platinum group metals

Platinum and platinum group metals were discovered as platinum arsenide and palladium telluride in ultramafic and noritic gabbros of the Chilas layered intrusive complex (Diamir District), from the layered noritic gabbros of the Jijal obducted block (Kohistan District), and from the Sakhakot-Qila ophiolite ("Dargai complex"), about 50 km north of Peshawar (PAGE et al. 1979, AHMED & BEVAN 1981, AHMED 1984, ASHRAF 1990, MILLER et al. 1991). In the Muslimbagh-Zhob Valley and Lasbela (Bela, 26° 15'N; 66° 17'E) areas, Pt and Pt-group metals have not been assessed in the chromite-bearing ultramafites yet but justify investigations. No tests have been reported on other metals of the platinum group, such as rhodium, osmium, ruthenium and iridium.

8.4 Non-ferrous metals

The **copper** deposit of Saindak is the largest known in Pakistan and has been investigated in depth. It is located about 9.4 km southeast of Fort Saindak (29° 14'N; 61° 37'E), Chagai District, in the northwestern corner of Baluchistan. This deposit is one of many mineralized rock bodies within a regional calc-alkaline "porphyry-belt" that extends about 480 km eastward across the Chagai District and is about 140 km wide (Hunting Survey Corp. 1960). It also extends westwards into Iran where it hosts the important Sar Chashmeh copper deposit (GOLESTANEH et al. 1978).

This calc-alkaline belt belongs to an island arc complex of Cretaceous to Oligocene volcanics and sediments. These rock formations were altered to hornfels by stocks and batholiths of granitic to dioritic composition, commonly tonalite bodies, and were intruded by dykes and sills as shown on a cross-section in Fig. 8.3. The alteration and subsequent weathering resulted in rubbly low hills in the so-called Sulphide Valley (AHMAD et al. 1972, MANZIES et al. 1974, TAGHIZADEH 1974, SILLITOE et al. 1977). Three main mineralized bodies of Saindak, with cross-sectional dimensions of 1,000 m x 200 m; 800 m x 200 m and 1,000 m x 400 m, have been thoroughly investigated, resulting in total estimated reserves of 412 million t, with Cu contents ranging from 0.336 % to 0.440 %, at a cut-off grade of 0.25 % Cu. Chalcopyrite is the major mineral (1.2 %), along with chalcocite (0.017 %) and traces of covellite, digenite and bornite. The mineralized stocks are hydrothermally altered, resulting in zonally arranged contents of Cu, Mo, Au, Ag, Fe (SHEIKH 1979). Exploitation of the Saindak deposit is in the planning phase.

An extension of the Saindak Sulphide Valley was discovered at Dasht-e-Kain (29° 33'N; 64° 29'E; MAHMOOD et al. 1984). The prospect shows an elliptical outline covering about 3 km^2. The mineralization is related to an altered tonalite porphyry stock emplaced in a diorite body, belonging to the Cretaceous Chagai intrusions, that intruded the Sinjrani Andesite. Cu-contents range from 1.200 ppm to 9,000 ppm, with a mean value of 483 ppm and an average Mo content of 21 ppm.

Many more mineralized areas are known from the Chagai District, mostly similar to the Saindak porphyry copper deposit and within a comparable geological framework. ZAKI (1969, 1975) listed 35 such areas including tuffs and agglomerates intruded by stocks of granitic, dioritic, and locally of syenitic composition, with Cu-ore minerals in shear zones, in quartz or calcite veins, or within contact aureoles, or filling fractures. Major Cu-minerals are chalcopyrite, malachite, azurite, chrysocolla and, rarely, native copper, with associated pyrite, magnetite, specularite and galena. More important locations are Amir Chah (29° 01'N; 62° 38'E), Dalbandin (28° 52'N; 64° 24'E), Nok Chah (28° 05'N, 84° 45'E) and Koh Marani (29° 35' 00"N; 66° 30' 00"E). A similar mineral association in the Bandagan Nala area, eastern Ras Koh (28° 49'N; 65° 03'E) involving the Kachakki Volcanics, has a 12 km wide mineralized zone with Cu content of 0.5 % to 1.0 %, and associated Au and Ag, Cu-Fe mineralization. At Chilgazi (29° 08'N; 64° 14'E), a Cu-Fe occurrence contains Cu ranging from traces to 0.5 % and, in places to 10.71 % (FARUQUI et al. 1970). In the Loralai District of Baluchistan, Cu-sulphides and carbonates are present near Ziarat (30° 23'N; 67° 44'E), and at Silad (30° 48'N; 66° 49'E) in association with stibnite in calcite veins cutting Late Miocene shales and sandstones, about 20 km northeast of the stibnite deposits of Qila Abdullah (30° 44'N; 66° 40'E).

In yet another type of mineralization, Cu-minerals with manganese and pyrrhotite are associated with chromite-bearing ultramafites of Late Cretaceous to Eocene age (HERON 1954), about 15 km, 20 km and 25 km north and northeast of Fort Sandeman (31° 21'N; 69° 29'E), and 17 km southeast of Nisai (30° 39'N; 68° 07'E), in contact zones between Paleocene shales and the ultramafites. Similarly, in the Waziristan Tribal area, Cu-minerals are found in serpentinized mafic-ultramafic bodies and in basaltic flows, such as near Datta Khel (32° 45'N; 69° 05'E) and Mami Rogha (32° 50'N; 69° 51'E); stratified massive Cu-sulphide mineralization has also been discovered (KHAN et al. 1982).

In the Chitral District, N W F P, widespread Cu mineralization is found in diverse geological associations, in quartzites and quartz veins, in shales and limestones; notable locations are at Dammal Nissa (35° 22'N; 71° 39'E), Mirkhani (35° 27'N; 71° 45'E), Shishi (35° 35'N; 71° 55'E), Drosh (Fig. 8.2) and Yarkun (36° 35'N; 72° 53'E). In the Dir District, N W F P, chalcopyrite, azurite, malachite and bornite, along with pyrite, are found in quartz veins and stringers in diorite, granite and hornblendic rocks at Ashnamal (35° 13'N; 12° 14'E), Lal Qila and Barwa Kambat (HUSSAIN 1974).

In Gilgit District, at Jotial Nala (35° 51'N; 74° 20'E), a 2 m wide zone in hornblendic gneisses and schists contains Cu-bearing quartz veins, and Cu minerals in veins which cut schists (Murkui, 36° 00'N; 74° 24'E). In the Abbottabad District, N W F P, malachite is present at Baldher, near Haripur (33° 59'N; 72° 55'E) in shales belonging to the Hazara Formation (SHAMS 1973). Within Parachinar (33° 54'N; 70° 06'E) Agency, Federally Administered Tribal Areas, fracture-filling Cu-bearing quartz veins are found in marbles, phyllites and basic intrusives, with Cu contents from traces to 5.6 %, together with galena and stibnite (AFRIDI 1968, MEISSNER et al. 1975). In the Punjab Province, Cu-mineralization has been observed at many places in Sardhai Shale and Warchha Sandstone of Late Paleozoic age in the Salt Range; the main minerals are malachite and cuprite with traces of native copper, forming nodules, specks and stains, with Cu contents as much as 0.47 % (QURESHI 1980).

Lead-zinc minerals from Allai Kohistan, N W F P, are associated with minor amounts of Cu and Mo at Lahor and Pazang near Besham (34° 56'N; 72° 52'E; ASHRAF et al. 1980). At Lahor, the banded rock series is composed of quartzites, magnetite-carbonates, pyroxenites with sulphides and calc-silicate skarns, intruded by Mo-bearing pegmatites. Ore minerals, which make up to 23 % of the rock, are sphalerite and galena, with minor chalcopyrite and traces of tetrahedrite. The mineralized zone is 2 m thick, containing about 0.55 million t of ore with Pb grades from 0.3 % to 5.5 %, and Zn grades from 0.7 % to 8.0 %. At Pazang, Pb-Zn sulphides are in environments comparable to Lahor; an estimated 0.3 million t of mineralized rock forms a zone as much as 1 m thick in the pyroxenite units. FLETCHER et al. (1986) claimed these to be stratiform deposits.

In the Swat District, N W F P, Pb-Zn mineralization consisting of galena and sphalerite is known from Ushu in the Falak Sair mountain, about 24 km NNE of Kalam (35° 34'N; 72° 43'E). The mineral-bearing quartz veins occupy fractures in diorites. The grade ranges from 12 % to 26 % Zn and 14 % to 57 % Pb, with traces of Sb (AHMAD 1959, TAHIRKHELI 1959).

Pb-Zn and Pb-Sb minerals are closely associated in the Chitral District, N W F P, at Pakhturi, Averit and Partsan; Cu is generally associated, too, along with traces of Au and Ag (CALKINS et al. 1981). At Pakhturi (36° 22'N; 72° 18'E), these minerals are in quartz veins as much as 25 cm thick, filling joints and fractures within calcareous quartzite, and are also disseminated in the quartzites. Zn content ranges up to 37 %, Pb up to 30 %, Cu up to 3 %; reserves are estimated to be 21.200 t of mineralized rock. The Averit showings are about 6 km southwest of Shoghat (Fig. 8.2), associated with a brecciated zone at the faulted contact between Reshun marble and phyllites (0.26 % to 46.6 % Pb, traces to 22.22 % Sb, traces of Au and Ag). The estimated reserves are 60,000 t but much more can be expected buried under scree and at shallow depths (HUSSAIN et al. 1974).

Other showings in the Chitral District (ZAKI 1969) are at Awi (36° 16'N; 72° 20'E), as Jamesonite; at Baig (36° 09'N; 72° 01'E), as galena; at Gahirat (35° 41'N; 71° 46'E), as galena with stibnite; at Imirdin (36° 03'N; 71° 23'E), as galena; at Parabeck (35° 59'N;

71° 24'E), as galena, with chalcopyrite and hematite; at Rain (36° 24'N; 72° 23'E), as galena with chalcopyrite, and at Tashcar (36° 03'N; 71° 48'E), as galena.

Lead mineralization in the Hazara District, N W F P, is reported from Hal (34° 11'N; 73° 03'E) and nearby Mihal and Paswal, north of Abbottabad, as veins in Precambrian slates and quartzites (SHAMS 1963), assayed at 73.6 % Pb, 0.50 % Zn, 0.25 % Cu, 1.70 % Fe, 0.17 % Ag, and 0.00017 % Au; reserves are not known. At Faqir Mohammad (35° 57'N; 73° 09'E), small amounts of galena are present in quartz veins cutting Eocene limestone. Some minor showings of galena are found in the Salt Range of Sargodha District, Punjab Province (HERON 1954).

There are some notable Pb-Zn localities in Baluchistan, related to hydrothermal activity in the Chagai calc-alkaline island arc environment of Cretaceous to Eocene age. At Dirang Kalat (29° 28'N; 64° 33'E), mineral veins are in a fault-related crush zone within andesite, composed of galena, sphalerite, siderite, malachite, limonite and calcite. Mineral contents range from 42.5 % to 51.3 % Pb, 2.1 % to 4.2 % Zn, with traces of Au and Ag. At Koh Marani, as much as 29.6 % Pb and 4.3 % Zn have been assessed. At Saindak, veins contain 12 % to 22 % Pb; some of these have been mined for local use (AHMAD 1962; ZAKI 1975).

The most important Pb-Zn deposits are 3 km southeast of Gunga (27° 44'N; 66° 35'E), Khuzdar District, Baluchistan (JANKOVIC 1986). The mineralization is of Mississippi Valley type, associated with a barite bed within the upper part of the Jurassic Zidi Formation (see Chapter 3.32) which is composed of dark grey limestone and light grey calcareous shale. There are 2 major mineralized beds namely the "Lower Zone", 30 m to 70 m thick, developed over 1.200 m along strike, with 3 % to 4 % Pb-Zn to a depth of 400 m, and the "Upper Zone" which is up to 80 m thick, containing 2 % to 3 % Pb and up to 8 % Zn. The mineralization is dominantly stratiform, with local epigenetic characteristics. The ore minerals are in disseminations, layers, lenses and patches confined to bedding, and local mineralized breccia. Galena is the major Pb mineral (0.1 to 1 mm grains), with inclusions of sphalerite, chalcopyrite, boulangerite and falkmanite, having 3,000 ppm Ag and up to 3,000 ppm Sb. The major Zn mineral is sphalerite, which is present both as tiny grains, and as larger grains that carry inclusions of galena, pyrite and marcasite.

Also of importance is the Pb-Zn-Ba deposit of Duddar (26° 05' 50"N; 66° 49' 38"), Lasbela District, Baluchistan. The mineral concentration covers an area of 3.87 km^2 at the eastern margin of the Mor Range, bounded by 26° 05' 50"N; 66° 49' 38"E / 26° 05' 24"N; 66° 49' 30"E. The mineralization is of sedimentary exhalative (SEDEX) type, likely to continue along stratification in carbonates, argillites and fine clastics of the middle Jurassic Shirinab Formation (LYDON 1989, HELMSTAEDT 1989). Calculations (ASHAM & BHUTTA 1991) resulted in 1,264,744 t of proved and indicated reserves containing 6 % Pb-Zn, and more than 1,200,000 t proved and indicated reserves containing more than 40 % Ba.

Deposits in a similar geological environment and lithological association are at Shekran (27° 50'N;66° 21'E), as replacement and fracture filling also in Jurassic limestone of the Zidi Formation (see Chapter 3.32). This deposit has been mined occasionally in the past. In the south, at Kanrach (26° 18'N; 66° 46'E), Honurki and Gacheri Dhoro, Las Bela District, Pb minerals are associated with barite within the Winder Limestone of Jurassic age (MOHSIN et al. 1983).

Tin ore minerals have not been located in Pakistan so far, although Sn has been reflected in analyses of skarns associated with the granite near Besham (34° 56'N; 72° 52'E), N W F P. As much as 600 ppm Sn is contained in magnetite-carbonate skarns, 0.01 % in siliceous-magnetite skarns, and 0.2 % in magnetite-silicate skarns (ASHRAF et al. 1980). In the associated Pb-Zn mineralization, however, Sn content is found to be as much as 6.0 % (CHAUDHRY et al. 1983).

8.5 Ferrous metals

Iron mineralization in Pakistan is of igneous and contact metasomatic, hydrothermal and sedimentary origin. Total reserves of more than 455 million t have been proved, 85.7 % being of sedimentary origin; none are exploited industrially as yet.

8.51 Igneous and contact metasomatic iron

The Chagai iron in the northwest Baluchistan Province is related to volcanic-sedimentary environment in the vicinity of acid to intermediate intrusive bodies, within the Chagai magmatic arc (Hunting Survey Corp. 1960, ALI et al. 1963, ZAKI 1975).

At Chilgazi (29° 08'N; 64° 14'E), three magnetite layers appear in the Early to Middle Cretaceous Sinjrani Volcanics. The upper layer consists of three magnetite lenses as much as 2 m thick, separated by and grading into andesite-epidote rock. Gangue minerals (10 % – 35 %) consist of quartz, chalcopyrite, pyrite, calcite, epidote and pyrophylite, locally also apatite. The mineralized rock bodies have a Fe content of 32 % – 55 % with an estimated reserve of 5.82 million t. The copper contents range from traces to 0.39 %, and gold from traces to 2.8 g/t (ZAKI 1975).

Hunting Survey Corp. (1960) reported banded hematite-magnetite at several localities scattered over a radius of 16 km around Mashki Chah (28° 02'N; 64° 24'E), about 64 km north of the Nok Kundi railway station. About 0.43 million t of mineral-bearing rock within the Sinjrani andesitic lava has Fe contents of 30 % to 50 %. At Amir Chah, two 1.2 m thick hematite veins were observed, both within the contact of limestone and Cretaceous Sinjrani Volcanics. Similar mineralization is present near Gorband and Kasanen Chapar (29° 06'N; 64° 18'E), composed of hematite-magnetite, with garnet and epidote in jasperoid gangue. Hunting Survey Corp. (1960) also reported magnetite-hematite ore at Darban Chah as 3 m to 5 m thick veins (about 1.13 million t).

AHMAD (1960) described two types of iron mineralizations in Kundi-Baluchap (29° 08'N; 64° 30'E), about 31 km northeast of Dalbandin, related also to igneous intrusions in limestone and lava flows of the Sinjrani Volcanics. The mineralization consists of veins as much as 2 m thick and is nearly 1.6 km long, composed of siderite with calcite and hematite-magnetite concentrations in a garnet-epidote rock. Total reserves are estimated to be 0.13 million t with Fe contents ranging from 43 % to 64 %. Twenty five discontinuous magnetite-hematite lenses are present in the Pachin

Koh area and two in the Lufto area, interspersed in the Sinjrani Volcanics, totalling 5.75 million t with 42 % - 58 % Fe to proved depths of 200 m – 350 m (ANWARUDDIN et al. 1984).

The Ras Koh Range in the southeast of the Chagai magmatic arc contains many iron mineral concentrations within the volcanic-sedimentary sequence of the Sinjrani Volcanic Group. AHMAD (1964) reported three locations near the head of Bandagan Kaur (28° 51'N; 64° 03'E), about 16 km southeast of Nok Chah. One is a vein of pure magnetite, 18 m thick and 180 m long, in indurated shale and volcanic rocks, intruded by a diorite-syenite. Another iron-rich zone is composed of hematite, 31 m long and 15 m thick, with an average of 24 % Fe and traces of copper. The third ore body is a magnetite-garnet mass in volcanic tuff with 35 % to 54 % Fe. The total reserves in these three bodies are estimated to be 180,000 t of iron ore.

At Kirana (31° 58'N; 72° 34'E) Hills in Sargodha District, Punjab Province, magnetite-hematite deposits are found in a volcanic-sedimentary sequence similar to that described from Chagai and Ras Koh, although of older age. The Kirana Hills constitute a northern exposure of the Indo-Pakistan Shield, composed of slates, quartzites and conglomerates with interlayered andesites, rhyolites and tuffs intruded by dolerites; the acid rocks were dated at 809–865 ± 20 mio years (DAVIES & CRAWFORD 1971). The iron mineralization is related to tuffaceous volcanics, and a thick sequence of mineralized strata has been penetrated recently during drilling (FARHAT 1989, REHMAN et al. 1990); the average Fe content is more than 45 %. Traces of Au were found.

A contact-metasomatic magnetite body at Dammal Nissa (35° 22'N; 71° 39'E), Chitral District, N W F P, investigated by KIDWAI & IMAM (1958) contains an estimated 6.5 million t. The iron minerals have replaced progressively the garnet-epidote assemblage formed owing to the intrusion of Mirkhani quartz porphyrite into the Ashret Limestone belonging to the Cretaceous-Eocene Koghozi Schist. The magnetite is pseudomorphous after hematite which remained at isolated spots; minor iron and copper sulphides and traces of V, Pb and Zn are also present. The composite iron-rich lens is as much as 23 m thick and extends nearly 130 m in length, with Fe contents ranging from 44 % to 65 %.

A similar magnetite-hematite body is found at Buni Zom, 72 km northeast of Chitral, formed due to contact effects of the Phargam Granite on the Cretaceous Reshun Marble. The mineralized body is as much as 4.5 m thick and is traceable over 3 km (ASRARULLAH et al. 1963).

Skarn-hosted magnetite concentrations were reported by ASHRAF et al. (1980) within the Precambrian Thakot Schist enclosed in the basement gneissic granite of Besham. Mineralized bodies are as much as 45 m thick and 250 m long, with an estimated reserve of 6.8 million t with Fe contents as much as 40 %. Associated elements, which are present in the maximum amounts indicated, are as follows: Pb 0.05 %, Zn 2.0 %, Sn 0.2 %, W 0.05 %, Mo 0.01 % and Bi 0.01 %. Minerals present include quartz, carbonates, garnet, barite, pyroxene, amphibole, epidote, pyrite, apatite and sphene.

ASHRAF et al. (1980) reported magnetite lenses, 1 m – 14 m thick and 3 m – 45 m long in hornblendite at Sher Kot and Kolai (73° 02'N; 34° 57'E) in the Allai Kohistan, northern N W F P (about 0.17 million t with Fe contents as much as 38 %). Additional magnetite bodies have been identified in the amphibole rock complex that forms part of the large Jijal (34° 58' 00N; 72° 00' 18"E) obducted block. Those at Kot and Lomoto in

Allai Kohistan, N W F P, are lenses 1 m to 2.4 m thick and 2 m to 6 m long containing about 51.323 million t, with Fe contents as much as 38 %.

Hunting Survey Corp. (1960) reported magnetite concentrations in the Zhob ultramafic intrusives near Naweoba (69° 22'N; 31° 35'E) and Inzarkai (69° 25'N; 31° 35'E) in Baluchistan.

8.52 Hydrothermal iron

Concentrations of hematite-siderite-limonite of hydrothermal replacement origin are found in the Khuzdar District, Kalat Division, Baluchistan, which form network veins in impure siliceous limestone of the Jurassic Zidi Formation (Hunting Survey Corp. 1960). Siderite constitutes the major primary mineral, later oxidized to hematite and both altered to limonite at higher level of the sections; calcite and quartz are the chief gangue minerals. Major concentrations are at Shekran (27° 51'N; 66° 23'E), the largest being 30 m to 60 m thick and more than 300 m long. At Monar Ṭalar (27° 44'N; 66° 35'E), the mineral concentration is a network of veins as much as 3 m thick below a barite zone, traceable for nearly 2.5 km (Fe content about 40 %). Total reserves of the mineralized rock in the area exceeds 10.3 million t.

8.53 Sedimentary iron

Sedimentary iron formations are present at a number of localities in the northern part of Pakistan. At some of these localities, extensive investigations have been undertaken to evaluate the resource potential.

At Pezu (32° 20'N; 70° 44'E), Bannu District, N W F P, the sedimentary iron forms four layers, the lower two in the Sembar Formation, and the upper two in the Lumshiwal Formation of Early Cretaceous age, separated by carbonaceous silty shales. These layers collectively have an average thickness of 4.5 m, extending over 3 km in length. The iron-bearing material is oolitic and represents a combination of limonite (48 %) and siderite (37 %), with glauconite and chamosite as minor constituents (6 %), the rest being quartz, mica and feldspar. The average Fe content is 31.3 %; reserves are about 12.6 million t (Pakistan Mineral Development Corp. 1973).

The iron formation at Rakhi Munh (29° 57'N; 70° 07'E) in Dera Ghazi Khan District, Punjab Province, is at the base of the Nari Formation of Oligocene age. It consists of an iron-rich bed as much as 3 m thick over a distance of 23 km, although only the middle 8.1 km portion is of economic interest. It is also a limonite-siderite material with Fe contents averaging 37.5 %, and has an estimated reserve of 14.5 million t (FARUQI et al. 1971).

At Mazari Tang (33° 45'N; 71° 55'E) in Peshawar District, N W F P, oolitic hematite forms a lenticular body within the Jurassic limestone; the estimated reserve of 0.5 million t has an average Fe content of 54 % (KHAN et al. 1974).

At Kalabagh (32° 55'N; 71° 32'E), an iron formation in the upper part of the Lumshiwal Formation of Early Cretaceous age has been studied intensively as a potential source of iron ore. The ore has variable mineralogical composition, called "Kuch type" (chamosite-siderite: 34.2 % Fe) and "Chichali type" (glauconite-siderite: 33.0 % Fe), with a transitional zone (glauconite-siderite-limonite-hydrohematite: 32.0 % Fe) of "Chuglan type". Reserves of all types are about 293 million t (ZAKI 1969, ASRARULLAH 1978). Although successful metallurgical tests were carried out by Krupp (Germany) and Irsid (France), industrial utilization could not be initiated.

At Langrial (33° 55' 33"N; 73° 07' 30"E), District Abbottabad, an iron-rich bed (6 m thick) is found at the contact of the Upper Cretaceous Nara Sandstone with the Lockhart Limestone of Paleocene age. Due to intense folding, the outcrop of this bed has been repeated 22 times within a distance of 45 km. Three mineralogical types are found: chamosite-limonite, hematite-limonite, and laterite-chamosite (KHAN et al. 1966). The Fe content is variable from 9 % – 50 %, with a total reserve of 28 million t. A hematitic claystone/siltstone layer at Galdanian (73° 19'N; 34° 01'E), also in District Abbottabad, N W F P, is between dolomite and limestone of Jurassic age; this layer has an average Fe content of 20 % and an estimated reserve of 60 million t.

Chromite is associated with ophiolites and ophiolitic mélanges that were tectonically emplaced during the Early Tertiary collisional episode between the Indo-Pakistan and Eurasian Plates. It is observed mostly in serpentinized dunites, harzburgites and peridotites as disseminated crystals, pods, veins, lenses and in some places as massive bodies. Mining of chromite started in 1903 after its discovery in 1901 (COULSON 1941) in the Zhob Valley, Baluchistan.

The most southerly chromite locality is near Bela (26° 15'N; 66° 17'E) in the Lasbela District of Baluchistan, which is mined recently at Sonaro (Fig. 8.3; 26° 21' 30"N; 66° 28' 40"E). Farther north in the eastern Ras Koh Range, Baluchistan, chromite is mined in the Bunap ultramafic intrusives that are folded along with the Sinjrani volcanic-sedimentary sequence (Hunting Survey Corp. 1960). The deposits are northwest and southwest of Bunap (29° 50'N; 65° 18'E) and in the Rayo Valley, amounting to more than 30,000 t, with Cr_2O_3 contents ranging from 47 % to 57 %, Cr:Fe ratio being 3:1 and less. Most of the exposed ore has been extracted (ASRARULLAH 1961, ZAKI 1969, 1975). Chromite in the western part of the Ras Koh Range is of no economic importance (BAKR 1964).

Of the Zhob Valley chromite deposits, over 10 million t of ore has been recovered so far. The ore bodies are associated with the Zhob Valley igneous complex, an ultramafic-mafic-basalt suite emplaced tectonically within Cretaceous sedimentary formations, and overlain disconformably by Eocene sediments. The complex covers nearly 3,200 km^2 between Khanozai (30° 36'N; 67° 20'E) and Fort Sandeman (31° 20'N; 69° 27'E), centered near Muslimbagh. The ultramafic suite is composed of dunites, harzburgites, peridotites, serpentinites and pyroxenites; chromite is associated with dunites, peridotites and serpentinites (Hunting Survey Corp. 1960, BILGRAMI 1964 a, ZAKI 1969, 1974, 1975).

Major mining areas southwest, south and east of Muslimbagh (30° 50'N; 87° 44'E), are named Khanozai, Jangtorgarh, Saplaitorgarh and Nisai. The chromite is in pods, lenses, layers, and as disseminated grains. Most of the production is from large, irregular pods that contain Cr_2O_3 ranging from 41 % – 53 % (average 45 %) and have a Cr : Fe ratio of 2.3 : 1 to 3.6 : 1 (average 3:1). The ore grade decreases from west to east; its Fe content increases with the Cr content, whereas the Al_2O_3 content is mostly low, which makes it suitable for metallurgical and chemical industries (BILGRAMI 1964 b, 1968,

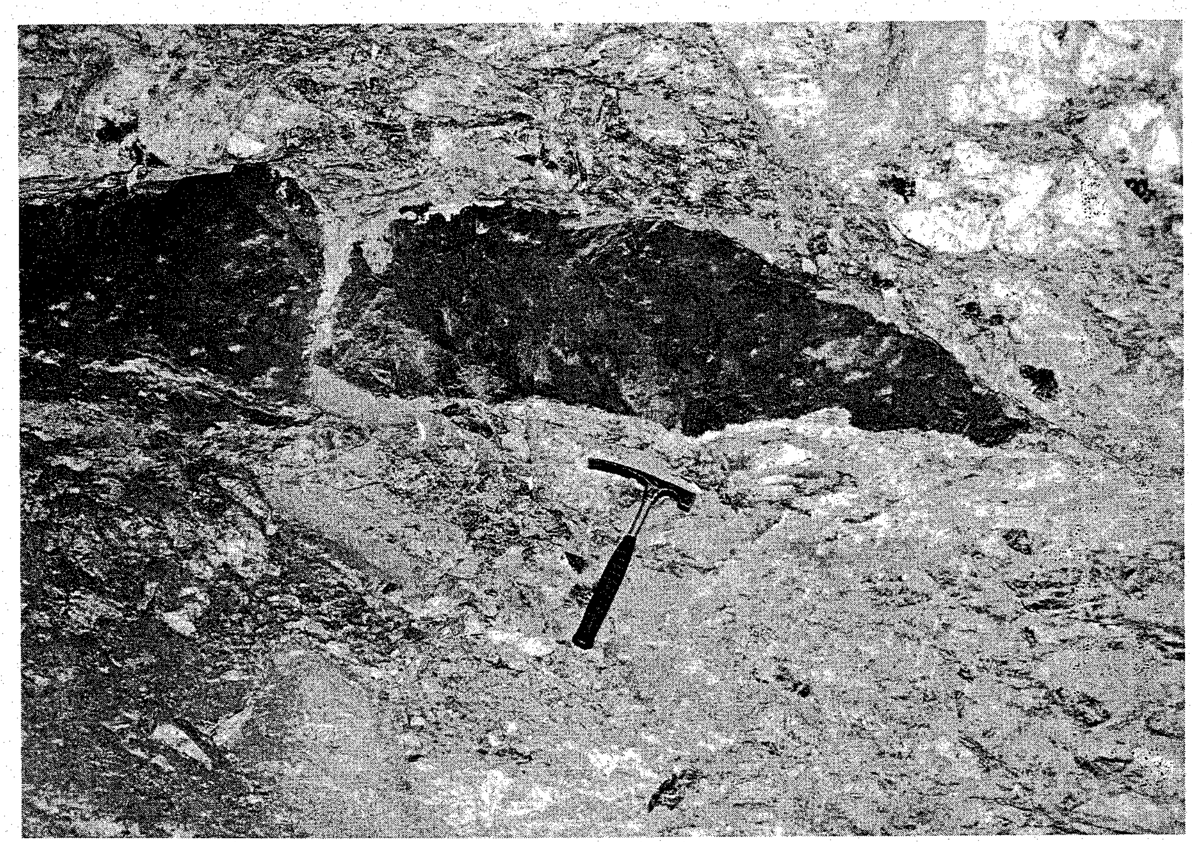


Fig. 8.3. Chromite lens in serpentinezed dunite at Sonaro (Photo: W. SCHILKA).

SHAFEEQ 1976, 1978 a). Structural variations include the orbicular variety that indicates liquid immisability (SHAMS 1964), and chemical variations locally include a high Fe+^{3} ore (SHAFEEQ 1978 b).

Chromite deposits near Fort Sandeman have a high content of Al_2O_3 (20 %), with Cr_2O_3 ranging from 36.7 % – 46.5 % and a Cr : Fe ratio from 2.4 : 1 to 2.5 : 1. The ore is of refractory grade (BOGUE 1962, BILGRAMI 1964 a). Farther north in the Waziristan Tribal area, adjoining N W F P, chromite bodies are small-sized (KHAN et al. 1982), with Cr_2O_3 contents ranging from 30 % – 40 %.

The Sakhakot-Qila ultramafic-mafic complex of Malakand Agency, west of Dargai (34° 28'N; 71° 54'E), also contains chromite. The complex is about 26 km long and 3 km to 6 km wide. Chromite is associated with dunite and, locally, with pyroxenite (ROSSMAN et al. 1972). The Cr_2O_3 content ranges from 24.3 % – 64.1 %, Al_2O_3 from 6.5 % – 42.7 %, and the Cr : Fe ratios from 1.4 : 1 to 4.5 : 1. Typically, the Fe variation is independent of the Cr variation (SHAFEEQ 1976, ZULFIQAR 1978, 1984). More than 50,000 t of reserves have been proved, with Cr_2O_3 contents averaging 40 %.

Metallurgical grade chromite has been discovered near Jijal, Kohistan District, N W F P, estimated at 0.6 million t of reserves with Cr_2O_3 contents ranging from 22 % – 55 % and the Cr : Fe ratio from 2.8 : 1 to 3.6 : 1 (ASHRAF et al. 1980). Farther north, thin layers of chromite, with Cr_2O_3 contents of 26 %, have been located in the dunite unit of the ultramafic-mafic layered complex of Chilas (35° 26'N; 74° 04'E), Diamir District (JAN et al. 1984). Ultramafic-mafic complexes are also present still farther north, near

Chalt (36° 16'N; 74° 18'E) in Gilgit District, and near Shigar (35° 25'N; 75° 43'E) in Baltistan District, carrying disseminated chromite.

Manganese mineral concentrations are known from 15 locations. The Lasbela manganese in the Kalat Division, Baluchistan, appears within a sequence of pillow basalts, jasperoid chert and shale of Cretaceous age, unconformably overlain by limestone of Eocene age, and cut by basic intrusions. Small concentrations are found in jasperoid chert at Gadani (25° 06'N; 66° 45'E), and at Haji Mohammad Khan Bent (26° 31'N; 66° 24'E), containing as much as 50.56 % MnO (ZAKI 1969). North of Gadani, about 40,000 t of rock containing as much as 42 % Mn was defined at Kharrari Nai (25° 54'N; 66° 45'E), within pillow basalts of Cretaceous age (KHAN & ABBAS 1973). At Khabri (26° 28'N; 66° 25'E), about 42 km northeast of Bela, a layer 2.7 m thick has an estimated 65,000 t of material (Hunting Survey Corp. 1960) containing 17.99 % to 23.99 % Mn, mainly as psilomelane and pyrolusite (ZAKI 1969).

Hunting Survey Corp. (1960) reported 5,800 t of manganese mineralization (40 % MnO) at Khan Kheo Nai (26° 11'N; 66° 34'E), about 26 km east-northeast of Bela; the manganese is hosted by a 3 m – 4.5 m thick jasperoid layer. About 3 km away along strike, 45,000 t of manganese-bearing rock at Siro (26° 17'N; 66° 33'E) have Mn contents ranging from 2.88 % – 31.72 % (MASTER 1960, ZAKI 1969). Hunting Survey Corp. (1960) also reported an estimated 11,000 t of manganese-bearing rock (36.85 % MnO) as a group of five deposits in a discontinuous jasperoid layer, 1 m – 60 m thick, at Kohan Jhal (26° 37'N; 66° 19'E), about 64 km north of Bela.

At Sanjro (26° 28'N; 66° 27'E), about 35 km north of Bela, Mn minerals are hosted by dolerite of the Bela Volcanics in a zone 1.2 m – 4.5 m thick, containing braunite as the major manganese mineral (AHMAD 1975). Mn contents range from 0.09 % – 30.02 % (BOGUE 1963), and Al, Cr, Ni, Cu, Zn, Co and Ba constitute as much as 1 % of the mineralized rock (estimated 21,000 t).

In the Zhob District, Baluchistan, small concentrations of manganese are present at Naweoba (31° 33'N; 69° 22'E) north of Fort Sandeman and at Waltoi Rud (30° 40'N; 68° 01'E), about 16 km south of Nisai. Both deposits are in the Parh Group rocks of Late Cretaceous age, associated with pillow-lavas intruded by ultramafic bodies.

Small manganese concentrations are also present in the Chagai District, Quetta Division, as nodules in the Cretaceous Humai Formation, such as at Nushki (29° 43'N; 66° 01'E). Also at Sotkinoh Hill in the Ras Koh Range, 3,200 t of manganese ore (40 % to 50 % MnO) were defined in a fracture zone (90 m long and 1.5 m wide) in the Paleocene volcanic-sedimentary Rakhshani Formation (Hunting Survey Corp. 1960).

Sedimentary manganese minerals are present in the Hazara District, N W F P, at Galdanian (36° 16'N; 73° 19'E), about 16 km northeast of Abbottabad. Here, the manganese is in the so-called "red-bed formation" within the carbonate-quartzite sequence of Permo-Carboniferous age (ALI et al. 1964, QURAISHI et al. 1960), traceable for over 2 km with an average thickness of 3 m. The manganese minerals are pyrolusite and psilomelane mostly as coatings on fractures in brecciated limestone; hematite is associated.

At Chur Gali (34° 18'N; 73° 28'E) lenticular bodies of manganese mineralization, 3.5 m wide and as much as 75 m long, are present about 8 km north of Galdanian, also in the "red-bed formation". The average Mn content is 28.75 % and Fe content is 18.55 % (NISAR et al. 1968). About 14 million t of ore has been estimated.

Manganese concentrations have been reported also from Thal (33° 22'N; 70° 35'E), 112 km west of Kohat, associated with a cherty hematite zone 6.6 m to 2.5 m thick, underlying limestone of Cretaceous age (ZAKI 1969). Many Mn-showings have been reported from the Waziristan area, N W F P, such as small lenses and stringers, 3 m to 8 m thick, in a contact zone between volcanics and cherty shale and limestone (KHAN et al. 1982).

Molybdenum is collected as a by-product of metatyuyamunite processing of uraniferous sandstone in the Dera Ghazi Khan (30° 09'N; 70° 30'E) area, Punjab Province. Mo is present also in the copper porphyry of Fort Saindak (29° 14'N; 61° 37'E), Baluchistan (about 30 t of recoverable molybdenite; SHEIKH 1979). Other copper porphyries in Baluchistan (ZAKI 1975) contain Mo as well. At Khan Abbas Banda and Pajia near Oghi (34° 31'N; 73° 01'E), powellite (0.2 % Mo) is found in thin quartz-feldspar stringers inside the Susalgali granitic gneiss (SHAMS et al. 1966). North of these localities, Mo is present in lime-silicate skarns, altered granite facies and pegmatites associated with Besham Granite, ranging from traces to about 1 %; in the associated Pb-Zn concentrations, the Mo content rises to 3.24 % (ASHRAF et al. 1980).

Tungsten minerals were first reported by ZESCHKE (1959) from Siran river sand, Pakhli Plain, Mansehra District, N W F P. Primary tungsten (powellite, scheelite) concentrations were located by SHAMS et al. (1967) from Auran and Lundi east and northeast of Oghi (34° 10'N; 74° 19'E) in the Hazara District, N W F P. The sparse ore minerals (3.2 % W in relatively rich patches) appear in pegmatites and aplites traversing the Susalgali granitic gneiss of Precambrian age.

Placer scheelite is known from Indus river sediments along almost its entire length from the Northern Areas down to Kalabagh in the Punjab Province. In the Northern Areas, Austrominerals (1976) estimated a total of 96 t of detrital tungsten minerals in about 40 million t of placers.

Promising W mineralization has been found recently in the Miniki Gol area, Chitral District, N W F P, where scheelite appears in different host rocks, mainly in an albite-quartzite that crops out over 5 km length. Another discovery of W mineralization is near Amalaf (29° 18'N; 61° 37'E), Baluchistan Province (SIDDIQUI et al. 1986), in a pyroclastic sequence and a quartz porphyry belonging to the Saindak Formation of Eocene age, in the Chagai calc-alkaline magmatic arc (SILLITOE et al. 1977). Mineralization has resulted from xenothermal alteration, represented by tungstite and scheelite, with associated Mo and Sn minerals.

Nickel minerals have been discovered, mostly related to ultramafic complexes. The "ophiolite nickel" is present as pentlandite, millerite and polydymite in serpentinites that originated from peridotites and pyroxenites. In the mineralized zone, average NiO content is 0.4 %, against a background value of 0.2 % (CHAUDHRY et al. 1980). SHAFEEQ (1981) reported 0.28 % - 0.32 % Ni in the serpentinites of Souch (34° 55'N; 73° 40'E) in Kaghan Valley, Mansehra District, N W F P; Ni-bearing minerals, heazlewoodite and pentlandite, are interstitial to the silicate minerals. Similarly, the ultramafites of

Muslimbagh, Zhob District, Baluchistan, also contain as much as 0.85 % NiO in some rock samples (BILGRAMI 1981, ZAKI 1974, JAN et al. 1984).

Cobalt is known only from some analyses of ores and rocks such as the Pb-Zn of Ghous Banda, 4 m north of Besham Qila (34° 56'N; 72° 52'E), N W F P, which show 0.005 % Co (NAWAZ et al. 1983).

8.6 Light metals

Aluminium is present as bauxite concentrations in close association with laterite (see also Chapter 9.1). Bauxite is found on top of the Cambrian Abbottabad Formation in outcrops near Sheikhan Banda, east of Abbottabad, N W F P, where the laterite component dominates (ALI 1959). In Chitral District, N W F P, a layer of lateritic bauxite 3 m thick is present about 5 km east of Reshun, resting on top of a quartzitic bed below the Devonian dolomites.

KHAN (1954) observed bauxite rocks at the base of the Jurassic Datta Formation in the Kala Chitta Range, north of Rawalpindi. In the Chhoi area, Attock District, bauxite includes a high-Al clay layer (HUSSAIN et al. 1972, ASHRAF et al. 1976). Extensive concentrations of bauxite are found at the base of the Tertiary rocks that mark an erosional unconformity between Permo-Carboniferous and Paleocene-Eocene Formations in the Salt Range, Hazara, Azad Kashmir and Baluchistan. ALI (1959) reported about 20,000 t of bauxite from northeast of Garhi Habibullah Khan (34° 24'N; 73° 24'E).

The Azad Kashmir bauxite reserves are estimated at 5.65 million t and much more are inferred. In the Muzaffarabad (34° 21'N; 73° 30'E) and Kotli (33° 31'N; 73° 54'E) areas, the bauxite is in pockets, lenses and irregular layers within a siliceous limestone bed that is present between Permo-Carboniferous limestone and Eocene Formations. A 1 m – 3 m thick layer of bauxite can be traced over 20 km along strike (ZAKI 1969). Twelve localities have been investigated in detail (ZAKI 1981), with Al_2O_3 ranging from 22.9 % to 69.3 %. At Dhanwan about 5 million t of bauxite were defined, with Al_2O_3 44.5 % to 60.5 %, and SiO_2 18.2 % to 40.1 %; at Nikial (33° 29'N; 74° 04'E): about 0.43 million t with Al_2O_3 41.0 % to 45.9 %, SiO_2 35.0 % to 44.3 %; at Kamroti (33° 36'N; 74° 04'E): about 1 million t with Al_2O_3 50.3 % to 69.3 %, SiO_2 8.6 % to 28.4 % (Engineers Combine 1976).

In the Kathha area of the Salt Range, Punjab Province, a bauxite layer more than 15 km long is present, marking an unconformity above the Permian limestones and below the Paleocene calcareous sandstones; the bauxite layer rests on laterite; Al_2O_3 contents range from 73 % to 38 %, SiO_2 from 9.12 % to 50 %. More than 60 million t of bauxite were defined (ASHRAF et al. 1972).

Bauxite of Early Jurassic age appears at Chhoi in the Kala Chitta Range and at Musakhel in the Salt Range in the Datta Formation. At Chhoi, the bauxite consists of boehmite and kaolinite whereas at Musakhel it is composed of diaspore and kaolinite (ASHRAF et al. 1976). A stratified chemical zonation exists such that the basal zone at Musakhel consists of 77 % – 81 % kaolinite and 10 % – 15 % diaspore, with 32 % Al_2O_3, 37.6 % SiO_2 and 12.0 % Fe_2O_3, whereas the upper zone has 4 % to 23 % kaolinite and 68.8 % – 87.9 % diaspore, with 68 % – 76 % Al_2O_3 and 2.5 % – 11.6 % SiO_2.

Lithium has been identified (BUTT et al. 1987) as lepidolite (4.24 % Li_2O) in pegmatites of Shangus, Gilgit District.

Magnesium is discussed under the heading "Magnesite" in Chapter 9.1 because it is dominantly used as an industrial mineral.

8.7 Special metals

Antimony mineralization is present in Paleozoic slates in Lutkho Valley of Chitral District, as stibnite intimately mixed with quartz in veins 0.6 m–1.2 m thick over a strike distance of 2.5 km. Main concentrations are at Krinj (23° 45' 00"N; 71° 45' 00"E; Fig. 8.4) and Averit, whereas minor findings are at Momi and Arkari (ZAKI 1969, CALKINS et al. 1981); total reserves are estimated to be 21,000 t of Sb ore.

Vein-type antimony is present within oxidized zones of slates 24 km northeast and 40 km east of Qila Abdullah (30° 43'N; 66° 38'E) in the Quetta District, Baluchistan. The mineralization consists of stibnite and valentinite in a gangue of quartz, calcite, limonite and hematite, making discontinuous lenses in oxidized zones, 15 m thick and 600 m long, within an area 6.5 km long and 0.8 km wide. The Sb contents range from 5 % to over 30 %; high grade ore was assayed as more than 54 % Sb, with Ba (10.73 %), Fe (3.36 %), Pb (0.3 %), As (0.22 %), and traces of Hg, Cu and Zn (ZAKI 1975); reserve estimates are nearly 100 t of Sb ore. Smaller concentrations of antimony are reported from the Zaimukht Hills, north of Thal (33° 22'N; 70° 35'E) in Kurram Valley, Federally Administered Tribal Areas.

Arsenic mineralization is present north of Lundku and Mirgasht (36° 26'N; 72° 17' 30"E) in the Tirich Mir Valley, Chitral District (ALI 1953), related to dolerite dykes that cut a limestone and calcareous shale sequence; orpiment and minor amounts of realgar are close to the dykes (ZAKI 1964). The ore is of good quality and has been mined over the last 50 years, with variable production. Many smaller arsenic bodies are known from Chitral under similar conditions of formation but at higher altitudes.

Orpiment and realgar are present at Chapursan, about 50 km north of Baltit (36° 20'N; 74° 31'E), Northern Areas. In Gilgit, arsenopyrite crops out in the Dainyor and Jutial Nalas, north and southwest of Gilgit respectively.

Bismuth and **cadmium** have been identified, but only in some analyses. For instance, Pb-Zn minerals in altered and silicified granites of Besham Qila (34° 56'N; 72° 52'E), Kohistan District, N W F P, show up to 0.80 % Bi and up to 0.2 % Cd (ASHRAF et al. 1979).

Mercury has been found thus far in traces only, such as from the Pb-Zn-Fe sulphides of Gunga District, Khuzdar, Baluchistan (JANKOVIC 1986).

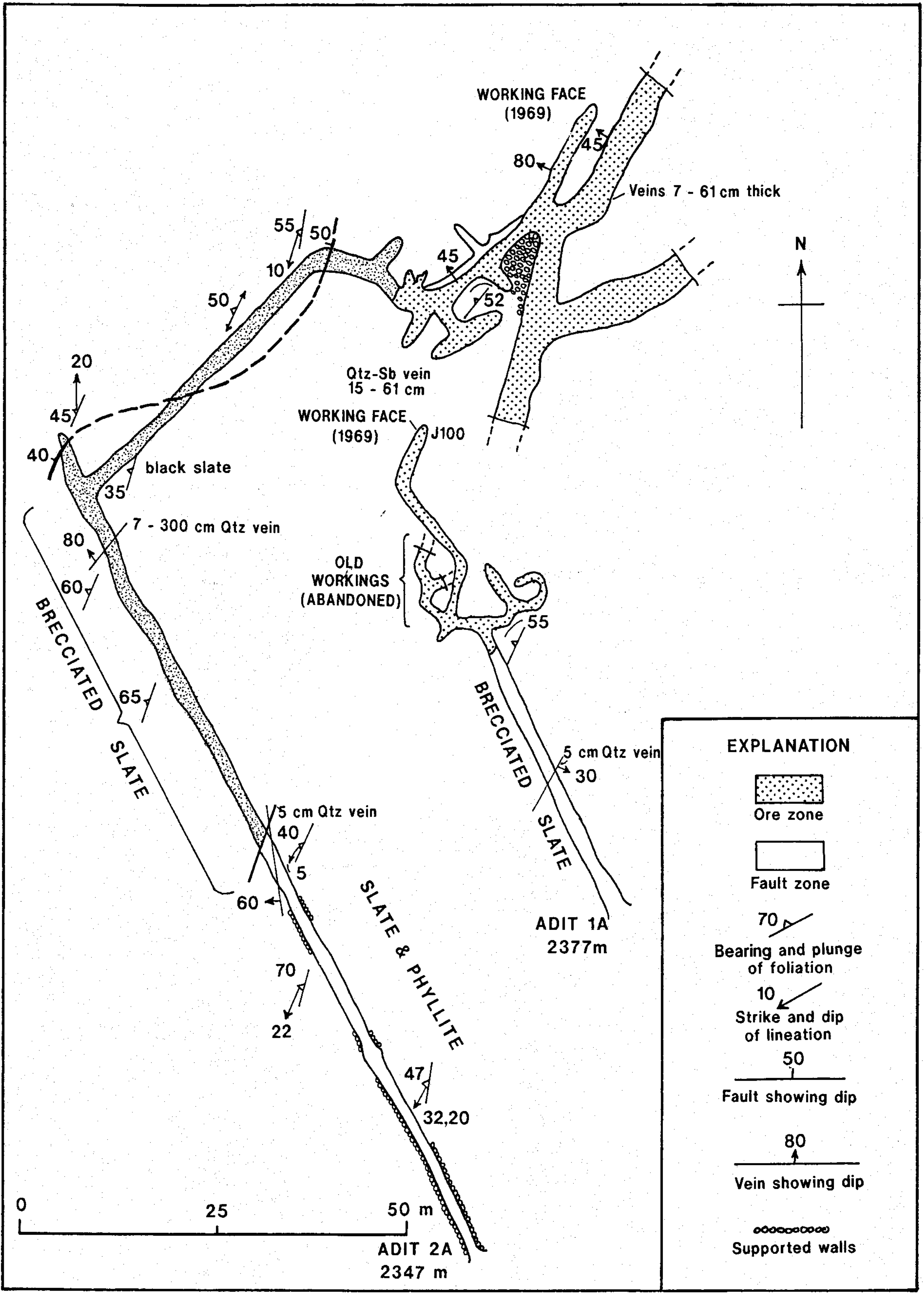


Fig. 8.4. Plan map of Krinj (Kamal Gol) Mine, Chitral, Quartz-stibnite veins alternating with slate (after CALKINS et al. 1981, fig. 6).

8.8 Rare Earths

Rare Earths have been reported from northern Pakistan, mostly from carbonatites associated with alkaline complexes, such as given below (SIDDIQUI 1967, ASHRAF et al. 1977):

	Ce	Y	La
Naranji Kandao, Koga, Swat District	0.070 %	0.005 %	–
Sillai Patti, Malakand Agency	–	0.020 %	0.040 %
Loe-Shilman (34°13'32"N; 70°56'00"E), Khyber Agency	–	0.006 %	0.055 %

From the Koga alkaline complex, ASHRAF et al. (1987) reported as much as 0.02 % La and 0.005 % Y in the nepheline syenites and the alkaline granites. ZULFIQAR (1986) observed Ce in the monazite-bearing chlorite schists in the Sakhakot (37° 24' 00"N; 71° 56' 00"E) – Qila area of Dargai, Malakand Agency.

9. Non-metallic raw materials

(Friedrich K. Bender)

Non-metallic raw materials include industrial minerals, stones and earths, sodium, potassium, magnesium and other easily soluble salts and their aqueous solutions and brines, as well as precious and semiprecious stones (Fig. 8.1, locality map). Heavy minerals and pyrite are also discussed here because they are mainly used for chemical industries rather than for metal production.

Table 9.1. Reserves and production of major non-metallic raw materials (after Shams & Khan 1987).

	Reserves (in tonnes) (1985)	Production per year (in tonnes) (1984 – 1985)
Barite	7,500,000	21,136
Bauxite-Laterite	74,000,000	2,035
Bentonite	100,000	2,303
Celestite	320,000	680
China Clay	4,900,000	816
Dolomite	"very large"	120,933
Feldspar	"not known"	5,661
Fire Clay	> 100,000,000	76,551
Fluorite	100,000	5,736
Fullers' Earth	"fairly large"	12,816
Gemstones	"not estimated"	169,013 carats
Gravel	"very large"	45,000
Gypsum	350,000,000	403,260
Limestone	"unlimited"	4,646,981
Magnesite	130,000	3,137
Marble	"fairly large"	141,835
Ochres	> 100,000,000	676
Rock Phospate	> 30,000,000	522
Rock Salt	> 100,000,000	573,558
Silica Sand	"very large"	115,346
Soapstone	600,000	17,192
Sulphur	> 1,000,000	1,134

The economic importance of non-metallic raw materials increased considerably with the industrial development.

Substantial reserves of some of these natural resources have been identified, and the potential of a number of them is considered to be high (Table 9.1). Additional non-metallic raw materials are believed to exist, considering the favorable geological conditions. Resources of limestone and dolomite for all industrial and agricultural requirements, as well as resources of gypsum and rock salt, are practically unlimited. This applies also for bloatable argillaceous material for light-weight aggregate production which will probably play an important role for the building industry in future. The increasing demand for sand and gravel can be met by the supply close to the fast growing population centers.

9.1 Industrial minerals

Asbestos

Asbestos localities were described by HERON (1950, 1954), QAISAR & KHAN (1969), AHMAD, Z. (1969) and HAMIDULLAH (1984). They occur in

- Baluchistan: Small veins of chrysotile asbestos in ultrabasic rocks south of Wad in Kalat District, near Muslimbagh in Zhob District; at Zozha Hill about 22 km from Fort Sandeman on the road to Shingar, and other locations north of Fort Sandeman; amphibole asbestos in an ultrabasic sill in the area north of Muslimbagh, and 2 km northeast of Jalat Kili, near Naweoba, and also north of Fort Sandeman;
- in the North West Frontier Province: Small veins of slip-fibre chrysotile asbestos in limestone at contact with an intrusive epidiorite, on the side of the road from Char Bagh Fort (34° 07'N; 71° 07'E) to the Kafir Kot Piquet Post, Kyber Agency; in serpentinite intruding shales about 2 km south of the Boya Scout Post (32° 57' 30"N; 69° 55' 30"E) and from Kaniguram (32° 31'N; 69° 51'E), Waziristan.

Apparently, none of the asbestos occurrences are of commercial interest.

Anhydrite

Anhydrite is not distinguished in the information available and only mentioned together with gypsum (AHMAD 1969, BILGRAMI 1982, BILGRAMI & FARAH 1986). Important gypsum/anhydrite deposits are located

- in the Dera Ghazi Khan Hills, Saidu Wali (Sulaiman Range); estimated reserves > 10 mio t,
- south of Kohat (associated with rock salt; estimated reserves about 5 mio t,
- Spin Tangi, Sibi District (Baluchistan, estimated reserves 0.4 mio t),
- Chamalang, about 11 km southeast of Chamalang village (Loralai District); estimated reserves approximately 7 mio t,
- Daudkhel area, gypsum and anhydrite associated with the evaporite facies of the Lower Eocene Sakesar Limestone; estimated reserves > 55 mio t.

The geological setting and characteristics of these deposits are discussed under the heading "Gypsum".

Barite

Stratabound barite deposits, commonly associated with fluorite and with base metal sulphides, are found in the north-trending Kirthar and Sulaiman Ranges (Fig. 8.1; see also Chapter 8). They are within medium- to thick-bedded, partly reef-bearing limestones of Middle to Late Jurassic age. In a few localities, the mineralization is in Jurassic sandstone (Bankhari; 26° 14'N; 66° 27'E), or in Early Cretaceous shale (Nako Pabni; 26° 46'N; 66° 31'E). The main characteristics of these deposits are summarized in Table 9.2.

Deposits containing barite as the dominant ore constituent are observed in the south (Lasbela), barite together with fluorite in the central part of the distribution area (Khuzdar; 27° 47'N; 66° 35'E), and fluorite as the prevailling ore mineral in the north (Zhob). The barite mineralization is concentrated within the stratigraphically well-defined Jurassic Windar Group in the Lasbela area, and in the Zidi Formation further north (MOHSIN et al. 1983). Apparently, most of the deposits are situated at structural paleo-highs.

The fact that the barite-fluorite-base metal sulphide mineralization is stratabound, and that ore lenses and nodules are not associated with any alteration of the host rocks points to a syngenetic origin for the deposits. Ore veins cutting across sedimentary layers, open space fillings by ore minerals, and unsupported host rock nucleii in the ore bodies, however, favour an epigenetic origin. SILLITOE (1978) and DURRANI (1980) classified the ore deposits as of Mississippi Valley type, formed along the northwestern margin of the Indian Shield which was occupied by the southern Tethys prior to its breakup from Gondwana. Very thick carbonates were sedimented in a neritic depositional environment during most of the Jurassic period. The tensional faulting at the initial stage of rifting of Gondwanaland was accompanied by a rise of the geothermal gradient which promoted brine movement. The reef facies played a role as supplier of sulphur for precipitating ore minerals from chloride complex brines. During compaction and diagenesis of the sediments, remaining connate brines were expelled laterally or towards higher horizons where their mineral contents were precipitated.

Celestite

Celestite deposits were described by BOGUE (1961), AHMAD (1969), MOOSVI (1973) and SHAH (1977) from the Surgan Anticline, at Thano Bula Khan (Sindh) and from Daud Khel (32° 53'N; 71° 43'E), Mianwali District (Fig. 8.1; see Chapter 8). Celestite ($SrSO_4$) is observed in the Laki Formation (Paleocene), and in the Tiyon Formation (Middle Eocene; see Chapter 3.42).

In the Laki Formation, the celestite mineralization seems to be confined to the major fault zones along strike, some of which can be followed over a distance of more than 25 km. Along fault zones, mineralization is in the form of steeply dipping veins composed of celestite and the gangue minerals calcite, locally hematite and limonite, and, rarely, a little pyrite. In some veins, brecciated limestone is the main gangue.

Table 9.2. Barite-fluorite-base metal sulphide deposits in the Kirthar-Sulaiman Ranges (after MOHSIN et al. 1983, slightly modified).

Locality	Minerals present	Form of mineralization	Host rock	Size, estimated reserves, annual production
Lasbela area				
Naka Pabni (26°46’N; 66°31’E)	barite pyrite	nodules and stockwork of residual nature	early Cretaceous shales	minor showing
Gacheri Dhoro	barite galena	bedded replacement	allochthonous Jurassic limestone blocks of Winder Group in melange	small; reserves 12,000 tons sporadic production.
Shiro Dhoro	barite galena quartz pyrite	lenticular bodies and veins	Winder Limestone and shale	small
Bankhari (26°15’N; 66°30’E)	barite galena	fissure vein following shear zone	Jurassic sandstone, Winder Group	small; reserves 2,000 tons in present quarry; sporadic production.
Kundi	barite	concordant replacement bodies folded with host rock	Winder Limestone and shale	small; reserves 14,000 tons
Khuzdar area				
Gunga (26°46’N; 66°31’E)	barite galena sphalerite	thick beds of barite replacing limestone	Zidi Limestone	large; reserves 1.4 million tons of barite, production 20,000 tons yearly
Shekran	barite fluorite galena siderite	bedded replacement and fracture filling	Jurassic sandy limestone Zidi Formation	small; lead mining in the past century
Kalat area				
Phad-e-Maran (southern Koh-i-Maran)	fluorite galena sphalerite calcite	concordant replacement bodies following sheared or unconformable Jur./Cret. contact.	Chiltan Limestone	large; exploration in progress: fluorite reserves estimated 100,000 tons: barite and sulphides have not yet been estimated
Chah Bali (Northern Koh-i-Maran)	fluorite calcite barite	veins and replacement along bedding planes	Chiltan Limestone	small; reserves were estimated as 1,400 tons however mines have already produced several times more
Dilband	fluorite calcite	replacement along bedding planes; cavity filling below unconformity between Jur./Cret.	Chiltan Limestone	medium; reserves 93,000 tons production 2,000 tons yearly
Zhob aarea				
Brunj Kili	calcite fluorite	veins or stringers	Alozai Group	trivial showing

In the Tiyon Formation, the celestite is stratabound and found as nodules and small lenticular pockets along bedding planes within marly beds which are interbedded with thin gypsum layers. These occurrences in the Tiyon Formation are apparently without economic importance, whereas celestite from the Laki Limestone yielded an approximate annual production of about 680 t of ore, the reserves estimated to be around 320,000 t (BILGRAMI 1982, BILGRAMI & FARAH 1986, SHAMS & KHAN 1987; Table 9.1).

MOOSVI (1973) explained the origin of the celestite ore as of synsedimentary type in the Tiyon Formation, during a period of lagoonal depositional environment. For the celestite in the form of veins along the fault zones in the Laki Formation, he assumed tectonic pressure and "squeezing" of strontium mineralized connate water in the underlying shales and marls. This would have caused the mobilization of mineralized formation water and re-precipitation of celestite in the fractures of the Laki Formation.

Feldspar

In Baluchistan, feldspar was reported by HERON (1954), FARUQUI et al. (1968), AHMAD (1969) and KHAN (1987): from the Raskoh Range in pegmatites and in ultrabasic rocks, about 18 km south of the Nushki-Dalbandin road; also, in the anorthosite within the main gabbro body approximately 2 km east of Zarghun Railway Station.

From the North West Frontier Province, pegmatites composed of quartz and feldspar in equal parts, were observed crossing the main road between Khaki and Susalgali, about 65 km from the Havelian Railway Station. About 23 km north of Battal near Rajdhawari (34° 00'N; 73° 06'E), several pegmatite bodies are found which contain large quantities of good quality feldspar. The most extensive pegmatite is more than 75 m in length and 12 m to 18 m wide. The middle portion of this pegmatite, 2 m to 3 m wide, is wholly composed of microcline. The amount of feldspar available from this pegmatite by open cast mining is well over 15,000 t. Mica and beryl are accessory minerals of interest. Feldspar in pegmatite veins intruding gneissic rocks was mentioned from Madian (35° 03'N; 72° 32'E), Swat, from Zidig Gal in Chitral, and around Dasu (35° 43'N; 73° 03'E) in Gilgit District.

Fluorite

Fluorite, like barite, is observed at scattered localities along the north-trending Kirthar-Sulaiman Ranges. Dominant fluorite mineralization in the Jurassic limestone is found in the northern part of the barite-fluorite-base metal sulphide belt, in the area of Kalat and Zhob (Fig. 8.1, Table 9.2).

Deposits of commercial interest are located at Dilband (29° 32'N; 66° 55'E; MOHSIN & SARWAR 1974, DURRANI 1980), and at Koh-i-Maran (29° 25'N; 66° 30'E) in the Kalat District (BAKR 1962, AHMAD 1969, MUSLIM 1972, MOHSIN et al. 1983), in the upper beds of the Upper Jurassic Chiltan Limestone (MOHSIN & SARWAR 1979). The fluorite mineralization forms concordant lenses and lenticles, but also forms fault and fissure fillings, veins and pipe-like bodies across the bedding of the limestone. Vugs filled with well-developed cubic crystals of fluorite are common. BAKR (1962) described fluorite veins which are 1 cm to 2 m thick in the Chiltan Limestone at the northern end of the Koh-i-Maran Anticline, whereas bedded deposits of fluorite, together with barite and base metal sulphides are found at the southern end of this anticline. Here, the zone of mineralization is observed at the contact of the Chiltan Limestone with the overlying Sembar Formation, a contact which marks a regional unconformity. HERON (1954) reported stringers of fluorite in the northernmost extension of the mineralized belt, in the Alozai Group at Zhob.

The fluorite mineralization in the Jurassic carbonate rocks apparently has the same genesis as the barite mineralization mentioned previously. An increase in the geothermal gradient during the initial stage of rifting was accompanied by movement of mineralized connate brines during compaction and diagenesis of the carbonates, and precipitation of the mineral content at suitable sites within the carbonate host rock such as bedding planes, solutional features below an unconformity, open fissures, joints and fault planes.

Glass sand

Major glass sand deposits were observed in the basal part of the Jurassic Datta Formation, from the Khisor and Marwat Ranges (HUSSAIN 1975). They are exposed for a length of 16 km between Paniala (32° 14'N; 70° 54'E) and Pezu (32° 25'N; 70° 55'E), with estimated total reserves of 20 mio t to a depth of 30 m (SIDDIQI 1973, RAFIQ et al. 1976, RAZA & IQBAL 1977). Glass sand is also known in the Datta Formation from the Surghar (ALI, S. T. et al. 1983) and Salt Ranges, as well as in the Late Paleocene Patala Formation, from the central and eastern Salt Range. Here, it ranges in thickness from < 3 m to > 20 m, with SiO_2 contents of > 95 % (AHMAD 1969, SHAH 1980).

HERON (1954) mentioned bedded glass sand in the Lower Cretaceous Lumshiwal Formation from near Mallakhel, and in the Salt Range associated with coal beds. Representative analyses revealed > 99 % SiO_2 and < 1 % Fe-oxides.

In Hazara, Mansehra District, high grade silica sand forms thick layers within a 150 m thick sequence of metamorphic calcareous sandstone resting on biotite-quartz schists, at Manda Kachcha (Munda Guchha; 34° 40'N; 73° 16'E; HERON 1954, ALI et al. 1964, HUSSAIN 1976, RAZA & IQBAL 1977).

In Quetta District, glass sand beds appear in the upper part of the Oligocene to Early Miocene Nari Formation, in the area of Ziarat (30° 26'N; 67° 17'E) and between Muslimbagh and Murgha Fakirzai (HERON 1954, Hunting Survey Corp. 1960, RAZA & IQBAL 1977).

In Sindh, various deposits were reported from near Unt Palan in Dadu District, at Thano Shah Beg in Oligocene sediments, between Meting and Jhimpir in Eocene rocks, and in the area of Jungshahi (24° 52'N; 67° 10'E; RAZA & IQBAL 1977). In the latter area, at a location called Dhandoti, glass sand with a grade of > 99.5 % SiO_2 was observed (HERON 1954, Hunting Survey Corp. 1960).

Graphite

HERON (1954) mentioned graphite from about 2 km northwest of Shah Salim and 1 km west of Momi in Chitral District. Graphitic shale and layers of graphite were observed near Shahid Mena (34° 09'N; 71° 17'E), and east of Lowara Mena in the Mullagori District, North West Frontier Province. Graphite is present in thin layers of carbonaceous schist near Agra in Malakand District; also in crystalline limestones at Nagar, Gilgit.

AHMAD (1969) reported a large number of graphite localities, in Gilgit Agency (Chalt, 36° 18'N; 74° 20'E; Chhelish, 36° 36'N; 73° 17'E; Moriwal Baikh, 35° 01' 30"N; 74° 25' 40"E, and others); in Peshawar Division (between Norang, 34° 53'N; 73° 38'E, and Babusar Pass; Sherwan, 34° 12'N; 73° 04'E; near Shahidmina, 34° 09'N; 71° 17'E), and in Quetta District (Sheikh Wasil, about 72 km southwest of Quetta). The Sheikh Wasil (29° 55'N; 66° 36'E) locality is on the crest of the Mashelakh Range and was temporarily mined. It is associated with tightly folded and fractured, laminated, red and black limestone, partly silicified, and carbonaceous layers in the Early Jurassic Shirinab Formation.

High quality graphite has been discovered on either side of the Neelam River (34° 56' 30"N; 74° 13' 08"E) in Azad Kashmir (GHAZNAVI 1981). Here, according to initial estimates, the deposits contain a total of 1.5 million t of ore (Mining Journal 1982).

Gypsum

Gypsum deposits are known in the area south of Kohat, at Daud Khel, Saidu Wali, Barkhan, Chamalang, Dera Ghazi Khan, Spin Tangi, Khatam and Hyderabad (Fig. 8.1), and in a number of other localities (HERON 1954, Hunting Survey Corp. 1960, AHMAD, Z. 1969). Only the more important deposits are discussed here.

In the southern part of the Kohat District (Peshawar Division), bedded to massive gypsum as much as 40 cm thick, with thin clay partings, is exposed in the Jatta Gypsum Formation of Early Eocene age; the Jatta Formation is conformably overlain by the Kuldana Formation (Early Eocene) and underlain by either the Bahadur Khel Salt, the Panoba Shale, or the Shekhan Formation, at different locations in the region. The reserves of the high grade gypsum are estimated to be 5 million t (RAZA & KHAN 1972, BILGRAMI 1982). This bedded deposit of gypsum is believed to have been percipitated from a concentration of solutions with a high content of SO_4^{2-} and Ca^{2+} ions in a restricted, shallow marine environment under arid conditions.

A large gypsum deposit is observed in the Dera Ghazi Khan (30° 08' 30"N; 70° 32' 18"E) hills, which form a part of the Sulaiman Range (AHMED, W. 1981). This deposit is within the Ghazij Group (Early Eocene) and is a product of the same depositional environment as the gypsum south of Kohat. A number of gypsum layers are as much as 8 m thick. Of similar origin and age are the deposits of **Daud Khel** (32° 53'N; 71° 43'E), (estimated reserves > 55 million t), and **Saidu Wali** (34° 45'N; 72° 10'E), where a gypsum sequence with a total thickness of more than 100 m is exposed (estimated reserves about 10 million t; AHMED, W. 1981, BILGRAMI 1982, BILGRAMI & IQBAL 1986).

The **Chamalang** (30° 12'N; 69° 25'E) deposits are located about 10 km southeast of the Chamalang Village in the Loralai District, where the gypsum is about 15 m thick, separated by shale and limestone interbeds. The reserves to a depth of about 30 m are estimated at 7 mio tons. Also at **Spin Tangi** (30° 47'N; 68° 08'E) in the Sibi District of Baluchistan, 2 m thick beds of gypsum are found in a sequence of green shales and nummulitic limestones of Early Eocene age (Ghazij Group). The reserves are estimated at 0.4 million t, to a depth of 15 m (AHMED, W. 1981).

The Salt Range Formation of late Precambrian ("Infracambrian") age contains anhydrite and gypsum associated with thick rock salt, shale, siltstone, sandstone, dolomite and oil shale. This Formation (more than 800 m thick at type locality Khewra, 32° 39'N; 71° 45'E, eastern Salt Range, Punjab) is widely distributed in the entire Salt Range area; it was drilled with a thickness of more than 2,130 m in an oil exploration well in the eastern Potwar basin (Dhariala-1). The exposed and near surface gypsum reserves were estimatd to be over 28 million t (AHMED 1981). The gypsum within the Salt Range Formation belongs to an evaporite cycle (or cycles) deposited in a restricted shallow-marine environment during a period (or periods) of increased evaporation under arid conditions.

Heavy minerals

Reconnaissance surveys for heavy minerals, involving studies of Quaternary geology and geomorphology, were carried out in parts of the Makran Coast, offshore area of the Indus Delta, Rann of Kutch and Thar Parkar Desert (PLATT 1962, SNEAD 1964, 1967, SNEAD & FRISHMAN 1968, WILHELMY 1968, SCHOTT et al. 1971, BEIERSDORF 1972, v. STACKELBERG 1972, MARCHIG 1972, ECKHARDT et al. 1973, GLENNIE & EVANS 1976, GAUDIE & SPERLING 1977, KAZMI 1977).

In the lowland along the 550 km-long Makran Coast, the following geological and morphological features can be distinguished:

- tidal-flat deposits; in existence from at least 6,500 years B.P.,
- younger systems of crescentic dunes; from 2,400 years to 6,500 years B.P.,
- younger systems of small longitudinal dunes; from about 5,000 years B.P. onwards,
- beach ridge systems; from more than 3,000 years to less than 6,500 years B.P. (Late to Middle Holocene),
- older systems of large longitudinal dunes; from more than 7,000 years B.P. (probably between 15,000 and 25,000 years B.P.)
- pediment surfaces and bahadas with fanglomerates; Pleistocene.

Heavy mineral concentrations (amphibole, barite, epidote, garnet, monacite, pyroxene, zircon, among others) were observed in the littoral facies zone, at the foot of cliffs, as foreshore to backshore placers, and as sub-littoral placers reworked by aeolian processes.

In the offshore area of the Indus Delta (SCHOTT et al. 1971, BEIERSDORF 1972, v. STACKELBERG 1972, MARCHIG 1972, ECKHARDT et al. 1973), the offshore mineral sands are strongly influenced by the sediment load of the Indus River, particularly south and southwest of the delta. In contrast to the fluviatile sands with heavy-mineral contents of more than 7 wt%, shelf sands contained in general less than 4 wt%.

MATTIAT & ZOBEL (1968) described a special case of zircon enrichment by foraminifera (*Edentostoma durrandi* MILLETT) witch purposefully incorporates zircon crystals. In comparision to normal sediment with about 3 % of zircon of the total heavy mineral spectrum, the foraminifers increase the zircon content to 86 % of their ingested mineral grains. Onshore, relatively high concentrations of heavy minerals were observed on barrier islands at the edge of the Indus Delta, mainly in marine-littoral sand bars (main heavy minerals: hornblende, garnet, epidote, apatite, zircon, toumaline). Heavy mineral enrichments were also observed along a Holocene marine terrace, and in dune sands in the Porali Plain near Las Bela (VERSTAPPEN 1968).

According to GLENNIE & EVANS (1976), parts of the Rann of Kutch existed already as islands in Early Tertiary which were modified by sea-level changes and feed-in of fluviatile and marine sediments during the Pleistocene and Holocene. PLATT (1962) and WILHELMY (1968) described the Rann of Kutch as a shallow, navigable bay ("Erinos Bay" at the time of Alexander the Great) which probably existed until the 8th century and dried up in the 14th century. Heavy minerals can be only expected below the Holocene pelites and evaporites exposed at surface.

To the north, the Rann of Kutch is bordered by the Thar Parkar Desert, with apparently ± E-W striking Quaternary faults with downthrows to the south. Different dune types were distinguished by VERSTAPPEN (1968, 1970). Some samples collected in the western part of the Thar Parkar Desert contained about 9 wt% heavy minerals, mainly hornblende, garnet, epidote, pyroxene, zircon, tourmaline, apatite and rutile. The content of the dune sand is much smaller than of the beach sands.

Kyanite

A schist containing as much as 30 % kyanite from near Oghi (34° 30'N; 73° 41'E) in southern Hazara was mentioned by HERON (1954). Kyanite-quartz veins in mica schist are present south of Jabba (34° 36'N; 73° 01'E) and 1.6 km south of Kuz Banda Rest House (34° 38' 30"N; 73° 00'E), in Hazara District. AHMAD (1969) also mentioned kyanite schists and kyanite bearing quartz veins close to Landakai (34° 39'N; 72° 08'E), about 30 km south of Saidu Sharif, Swat District.

Apparently, none of these occurrences meets the requirements for commercial production.

Laterite and bauxite

Laterite and bauxite are observed in close association and have been described together by HERON (1954), ALI (1959), ASRARULLAH (1959), Hunting Survey Corp. (1960), STANIN (1966), AHMAD (1969), ASHRAF et al. (1975), RAZA & IQBAL (1977), SHOW (1980), HASSAN (1984), ABBAS & HASSAN (1984).

Laterite with possibilities of the formation of high-grade bauxite (> 50 % Al_2O_3, < 4 % SiO_2) can be expected on old land surfaces with slight or no relief, exposed to long weathering periods, and little or no transport of the weathering products. The weathering may have occurred on any rocks with the exception of sandstone and ultrabasite.

Such conditions are met with

- in the Cambrian, on top of the Abbottabad Formation, near the village of Sheikhan Banda, east of Abbottabad,
- in the Devonian, between quartzite and dolomite, in Reshune Gol (Nal), 5 km northeast of Reshune Village, Chitral,

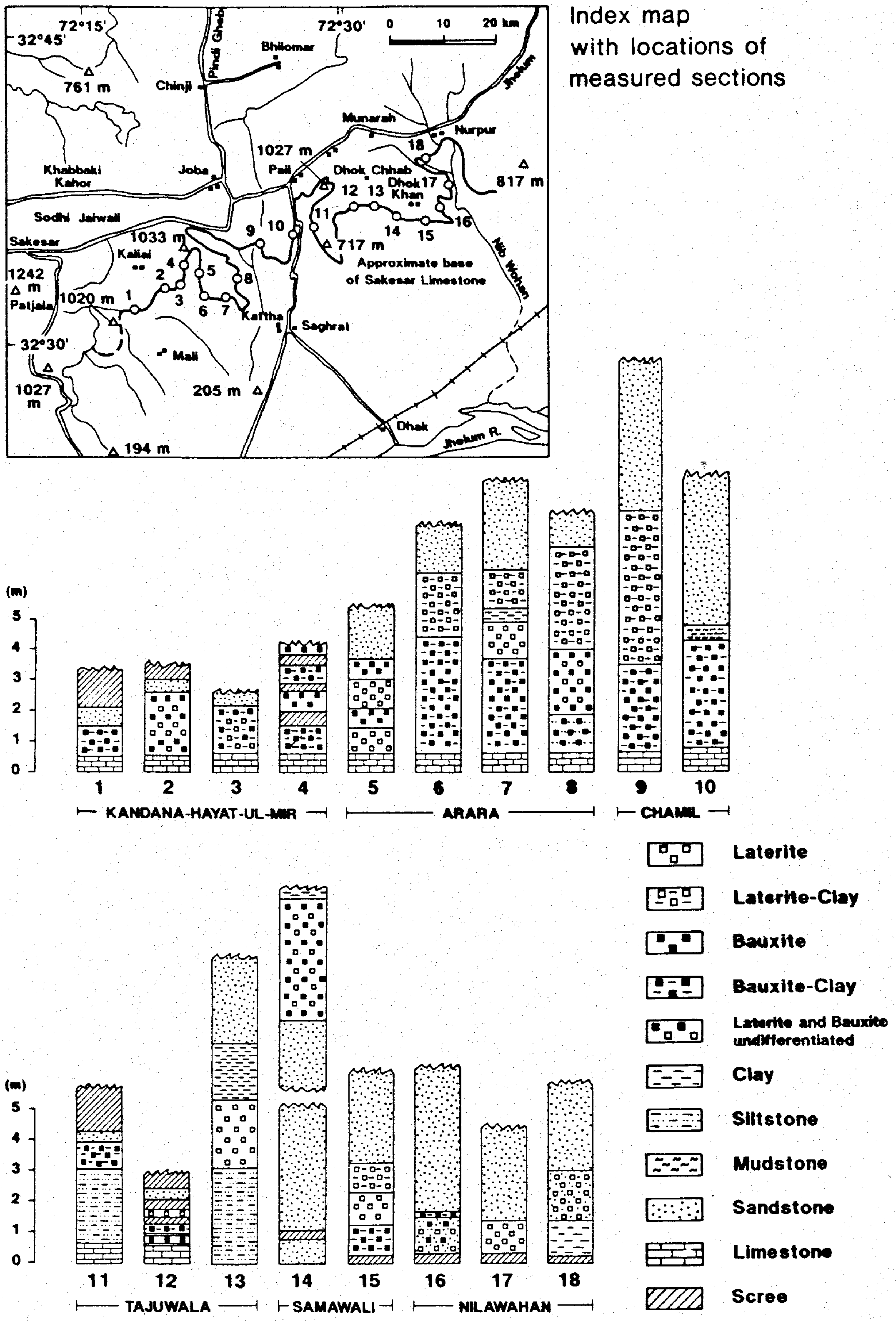


Fig. 9.1. Measured laterite-bauxite sections, base early Paleocene Hangu Formation (after SHAH 1980).

- in the Jurassic, at the base of the Datta Formation, at many localities in the Kohat-Potwar area (Kala Chitta Range, Zaluch Nala and Nammal Gorge), and, particularly,
- at the base of Tertiary rocks, where a regional, non-depositional hiatus existed during the Late Cretaceous and probably earliest Paleocene periods of time.

Laterite and bauxite at the base of the Tertiary sequence were observed in extensive areas in the Salt Range, northern Potwar, Hazara and Kashmir. SHAH (1980) described in detail the occurrences from the central Salt Range. Fig. 9.1 shows sections of the base of the Early Paleocene Hangu Formation measured in this area. Only small reserves of bauxite could be demonstrated as of ore grades $>50\ \%$ Al_2O_3, and none with $<4\ \%$ SiO_2.

Magnesite

Magnesite is here discussed because it is dominantly used as an industrial mineral for the manufacture of refractories, in special cements, and in the steel, paper and rubber industries, as well as in agriculture.

Crystalline magnesite ($MgCO_3$) is in general formed by replacement processes in dolomite or dolomitic limestone, cryptocrystalline (dense) magnesite by alteration of serpentinized ultramafic rocks. Both varieties are found in Pakistan. Among others, HERON (1954), Hunting Survey Corp. (1960), GAUHAR (1967), AHMAD (1969), ASHRAF et al. 1971, RAZA & IQBAL (1977) and AHMED (1981) mentioned or described deposits of magnesite.

Near the village of Sakhakot (37° 24'N; 71° 56'E), about 60 km north of Nowshera, dense magnesite is found in a number of veins in serpentinized ultramafic rocks. At Kumhar, 29 km northwest of Abbottabad and 3.2 km southeast of Sherwan, crystalline magnesite forms irregular lenses in grey dolomite and dolomitic limestone of the Early Cambrian Abbottabad Formation. Apparently, hydrothermal replacement resulted in MgO-contents ranging from 44.9 % to 46.7 %. The probable reserves were estimated to be about 1 million t. Dense magnesite veins associated with serpentinized dunite were observed at Nasai, about 32 km east of Muslimbagh in Zhob District. Reserves of the ore (MgO 45.4 %) were estimated to be about 60,000 t (AHMED 1981, p. 70). At Spin Tangi (30° 47'N; 68° 06'E), located about 5 km east of the Nasai railway station in Zhob District, massive, cryptocrystalline, pure white magnesite forms a steeply-dipping ore body about 80 m long with an average width of 4.50 m, in serpentinized dunite. Ore reserves of about 16,000 t have an average grade of 45.4 % MgO; limited open cast mining has occurred. Ore of the same type and quality is also found at Shabi Ghundi (30° 48'N; 68° 10'E), about 9 km west of Spin Tan, and at Tlerai Mohammed Jan (30° 53'N; 67° 42'E), 12 km south of Muslimbagh. At Sra Salawat (30° 40'N; 67° 53'E), about 32 km south of Muslimbagh, magnesite was observed in dolomite host rock of Eocene age which unconformably overlies ultramafic rocks. The estimated reserves of apparently high grade ore of one of the ore bodies are in the order of 16,000 t.

Dense magnesite of the vein type in ultramafic rocks was also observed in Kakru (27° 43'N; 66° 09'E), about 58 km WSW of Khuzdar, and at Loya Na Pani (27° 15'N;

66° 20'E), both in Kalat Division. These small deposits contain relatively low grade ore (32.8 % MgO). Similarly, at Sinchi Bent (26° 30'N; 66° 21'E), narrow veins of dense magnesite are exposed in an area of 15 m x 100 m.

Mica

There are a great number of mica varieties in Pakistan; the principal variety for industrial use is muscovite. HERON (1954), AHMED, W. (1962) and AHMAD (1969) listed a great number of muscovite-bearing pegmatites from the following localities:

Azad Kashmir and Gilgit Agency
- near Baltit (36° 15' 20"N; 74° 25'E), Hunza State
- Surgin Nala, tributary of Nilan River (sheet mica),
- north of Haiderabad in Hunza State, and near Dazu (35° 20'N; 73° 20' 10"E) in Baltistan (sheet mica).

Peshawar Division
- near the village of Mogh in the Lalkho Valley, 32 km east of Chitral,
- at the Kasu side of the Shera Shing Hills, about 12 km north of Drosh (35° 34'N; 72° 52'E),
- near Khadan Village in Dir State (sheet mica),
- at Khadong Banda (33° 42'N; 71° 50'E), about 25 km north of Chakdara; sheet mica-bearing pegmatites in gneisses

Hazara District
- near Bagarian (34° 33'N; 73° 10'E), west of Belega,
- near Hawa Gali (34° 29'N; 73° 06'E),
- about 2 km east of Rajdhawari (34°N; 73° 06'E), about 23 km north of Battal; sheet mica-bearing pegmatites in granite, gneiss and schist which consist mainly of perthite, plagioclase and quartz, and accessory minerals muscovite, tourmaline, beryl, garnet, billibinite, biotite and epidote. Two of the Rajdhawari pegmatites were temporarily quarried for beryl, feldspar and quartz.

Mineral pigments (ochres)

Red and yellow iron oxides as pigments for the manufacture of paints are extracted in small quantities at Uchhali (32° 32'N; 72° 02'E) and near Kutki (32° 59'N; 71° 21' 07"E). They are in beds as much as 1 m thick in the Jurassic sequence of the Cis-Indus Salt Range (Punjab). Such deposits have been noted also in the sandstones northeast of Pirkahar (32° 39'N; 72° 43'E). Some of the softer, bright red, ferruginous material in the lateritic or pisolitic rocks from the Paleocene and mid-Jurassic sequences of the western Salt Range are locally used for the manufacture of ochres (HERON 1954).

Ochre-bearing beds were observed also at the base of the Early Eocene Laki Formation lying unconformably above the upper Ranikot Group. They are located west of Jhol Dhaund (24° 52'N; 67° 56'E), around Harmon Mohatta coal mine, west of Sonhari Dhand (25° 00'N; 68° 04'E), and at some additional places in the Thatta District (AHMAD 1969).

Phosphate

Sedimentary phosphate deposits occupy more than 160 km^2 in the Abbottabad area, Hazara District (SHAH 1977, GHAZNAVI & KARIM 1978 a, 1978 b, LEE 1980, HASAN & GHAZNAVI 1980, HASAN et al. 1985, REHMAN et al. 1990). The deposits are in impure limestone in the upper part of the Abbottabad Formation (Sirban Formation), in a thick sequence of alternating dolomite/ limestone/ marble/ quartzitic sandstone of (Early ?) Cambrian age. The ores contain carbonate fluorapatite (francolite), glauconite, dolomite, calcium carbonate, silica, iron oxides, and pyrite, and they range in grade from 10 % to 30 % P_2O_5. At Kalkul (34° 12'N; 73° 17'E), about 200 t to 300 t per month are produced by underground mining. Total reserves at Kalkul are about 1 x 10^6 t (McCLELLAN & HILL 1983). Mining has also begun near Largaban with about 2.5 x 10^6 t of estimated reserves; here, nearly 1 x 10^6 t of the reserves contain more than 25 % P_2O_5. The ore is in lenses and layers as much as 1 m thick that are generally somewhat variable in composition as well as in grade. The ore is hard to grind, and, because of the presence of reactive impurities (commonly dolomite), requires costly benefication processes (McCLELLAN & HILL 1983).

In the lower part of the Chichali Formation (Cretaceous), sandy and glauconitic shales contain phosphatic nodules with P_2O_5 grades between 5 % and 15 %, in the Kohat area, particularly between Khwari and Gandad Khwar (SHAH 1977). Additional showings of phosphorite mentioned by SHAH (1977) are as follows:

- Calachitta Range, near Chhoi, phosphatic limestone, Kawagarh Formation, Late Cretaceous;
- eastern and central Salt Range, phosphatic nodules sporadically in Patala Formation, Paleocene;
- Rakhi Gorge, Sulaiman Range, "phosphate indications" in the Paleocene Khadro Formation; in the basal part of the Eocene Ghazij Group, and in the Oligocene Nari Formation;
- Marri-Bugti Hills, phosphatic nodules and pebbles in the Late Cretaceous-Paleocene Moro Formation.

HERON (1954) described phosphatic nodules in "Upper Cretaceous shales" (= lower part of Paleocene Khadro Formation; IQBAL & SHAH 1980) from Pabni Dhora to Shah Bhilawal, exposed for about 60 km along the Pab Range, Lasbela District. The nodules have a content of up to 3.25 % P_2O_5; according to SHAH (1977), the content ranges between 5 % and 15 % P_2O_5. Some of these low-grade ores are easily to be exploited at surface. They might be suitable for direct use in agriculture and would not require benefication and chemical processing.

Pyrite

Pyrite is discussed here under non-metallic raw materials because it is used for the production of sulphur and sulphuric acid rather than for iron. The many pyrite localities reported so far are economically of little interest, either because of small reserves or of difficult access.

From Azad Kashmir and Gilgit Agency, HERON (1954) and AHMAD (1969) listed the following locations:

- North of Normal, near Peak Holtar (4,040 m) (36° 09'N; 74° 15' 05"E), pyriteous slate with concentration of pyrite as much as 25 %,
- about 6.5 km south of Normal (36° 09'N; 74° 15' 05"E),
- in Dainyor Nala (36° 01'N; 74° 15' 11"E),
- at the upper end of Dainyor Nala, near the snout of the Surgin Glacier,
- in Jutial Gol, about 9.5 km southeast of Gilgit.

Except for the deposit near Normal, pyrite is found in quartz veins as gangue mineral, commonly associated with galena, cuprite and tetrahedrite. At Jutial Gol, the pyrite zone in the quartz vein is as much as 1.90 m wide and extends for over 160 m, with available reserves of several million tons.

From Baluchistan, a small pyrite vein in a dolerite dyke is known about 500 m southeast of the village of Ghazhesi (30° 31'N; 67° 27' 48"E), at Shingarh north of Fort Sandeman, and at Bandagan (Chagai District). Here, massive pyrite is associated with magnetite and copper mineralization (HERON 1954).

Quartz

Quartz used for the manufacture of ferrosilicon, chromesilicon, silicon metal, quartz glass, pure silicon, and quartz with piezoelectric qualifications ought to be very pure (> 98 % SiO_2) to extremely pure (> 99.9 % SiO_2). Commercial deposits of these requirements have not been identified in Pakistan although quartz has been reported from many localities, (AHMAD 1969), including:

Gilgit Agency and Baltistan

- at Khaiber (36° 34'N; 74° 48'E), Morkhun (36° 37'N; 74° 52'E), Minapin Glacier (36° 11'N; 74° 33'E), Iskhere Valley (35° 47'N; 74° 48'E) and Hanuchal-Jotial area (35° 43'N; 74° 57'E); in pegmatites traversing biotite-gneiss and biotite schist in Dasu, Niesolo, the Shigar Valley and Shigarthang area of Baltistan.

Peshawar Division

- in Rajdhawari area (34° 00'N; 73° 06'E), Hazara District; massive quartz in pegmatites intrusive in granite, associated with feldspar, mica and beryl; one of the pegmatites contains over 811 t of massive quartz and was temporarily mined;
- at Chitta Batta (34° 22'N; 73° 16'E), on the Mansera – Gari Habibullah road, at Doga, and at Trangri in Hazara District; near Danda Village (34° 19'N; 72° 28'E) in Mardan District.

Sulphur

Sulphur has been mined occasionally on a small scale in the Sanni area, Kalat Division of the Kachhi District, Baluchistan (29° 02'N; 67° 29' 07"E; Fig. 8.1). According to MUSLIM (1971), MUSLIM & KHAN (1971) and KHAN & MUSLIM (1972), the sulphur is in veinlets, encrustations, fillings of pores in sandstone, and as replacement of calcareous matrix of sandstone, in three intervals in the Nari Formation (Oligocene). The upper, middle and lower ntervals are about 3.30 m, 1.30 m and 1.90 m thick, respectively, and consist of sulphur-bearing, gypseous, clayey sandstone, variegated sandstone and shale. In the area of the Sanni mine, the total reserves of ore with an average sulphur content of 45 % are estimated to be around 58,000 long tons capable of yielding approximately 26,000 long t of sulphur. COTTER (1919) and HAZEN (1929) reported the presence of tar in the lower workings of the mine then accessible. MUSLIM & KHAN (1973) mentioned a bore hole drilled in 1941-42 which penetrated a tar (asphalt) bed about 2.50 m thick. These authors believe that sulphur-reducing bacteria acted directly upon the organic material in the source rock. The generated hydrogen sulphide migrated through permeable and porous sediments, and, in contact with oxygen, native sulphur was percipitated in pores, fissures, vugs and other open spaces in the host rock.

Another major deposit of sulphur was mentioned by VREDENBURG (1901), and described by HERON (1954), AHMAD (1969), MUSLIM (1971), and others, from the extinct (Pleistocene) volcano Koh-i-Sultan (29° 07'N; 62° 47'E) in the Chagai District, Baluchistan. The ore is of solfataric origin, having formed during the final phases of volcanic activity. According to HERON (1954) and MUSLIM (1971), sulphurous exhalations are still active from fissures and surface outcrops of sulphur-bearing, altered porphyritic-andesitic lavas. The irregular and lenticular ore bodies are as much as 10 m thick and about 100 m in length, and vary considerably in grade. HERON (1954) mentioned an estimate of 50,000 t of proved reserves of ore containing > 50 % native sulphur, and 36,000 t containing 30 % to 50 %. MUSLIM (1971) estimated reserves of 738,000 t of 50 % grade.

HERON (1954), Hunting Survey Corp. (1960) and AHMAD (1969) listed the following, apparently minor, indications of sulphur without more detailed geological descriptions:

- in massive limestones of Late Cretaceous age at Draj Bent and Gokurt in the Bolan Pass area,
- in the area of intensely saline springs near Khan Berar (25° 29'N; 63° 03'N) west of Sonmiani (VREDENBURG 1909),
- at Golkurt near Korangi (25° 27'N; 64° 09'E) on the Makran coast,
- crystals of sulphur in the stalagmites deposited by hot springs at Khattan (29° 34'N; 68° 31'E) in Sibi District,
- and other small showings near Chappar, west of Kalat, and near Jiwani in Makran;
- associated with decomposed pyritous shale near Kushalgarh, Kohat District, at Luni-ki-Kassin (33° 36'N; 72° 01'E), at Panoba (33° 37'N; 71° 58'E), at Gunjali (33° 25'N; 71° 50'E), and in the upper nummulitic beds near Domunda (31° 36'N; 70° 14'E) in Sherani Country.

TIPPER (1921) observed indications of sulphur at the following localities:

- associated with a sulphurous spring near the village of Muzigram (36° 06'N; 71° 36'E), 32 km north of Chitral,
- from a hot spring, associated with gypsum, at Sor Pass (30° 15'N; 70° 33'E) in Dera Ghazi Khan District,
- at Sanghar Pass (30° 42'N; 70° 32'E), in beds probably of Eocene age on the south side of Gandahari Hill (29° 06'N; 69° 46'E) in Dera Ghazi Khan District,

- associated with oil seepages near Jaba (32° 52'N; 71° 44'E) in Mianwali District,
- east of the Margala Pass (33° 42'N; 72° 53'E),
- at Ghizri Bunder (24° 46'N; 67° 08'E),
- at Laki (26° 16'N; 67° 57'E) from hot springs,
- associated with hydrocarbons near Jacobabad.

Talc (steatite, soapstone)

Talc, a hydrous magnesium silicate, is mainly formed by alteration of Mg-bearing minerals in dolomitic rocks and ultramafic rocks. It is used for a great variety of applications in the ceramics, electroceramics, paper, paint, rubber, and pharmaceutical industries.

Exploitable talc deposits are present in a zone about 16 km long and as much as 2 km wide in the Sherwan area extending from Hariala across the Siran River to Kharan, about 40 km west of Abbottabad, Hazara District. They form irregular bodies and veins in sheared and fractured dolomite within the Early Cambrian Abbottabad Formation (HERON 1954, ALI et al. 1967, CALKINS et al. 1967, AHMAD 1969, CALKINS et al. 1969, RAZA & IQBAL 1977). The indicated reserves are thought to be in the order of 200,000 t (AHMAD 1969); the production is about 7,700 t annually (BILGRAMI 1982).

Smaller deposits of talc were reported from Kharwala Nala (34° 02'N; 69° 54'E), about 24 km northeast of Parachinar, near the Afghanistan border in Kurram Agency, and near the village of Daradar (33° 57'N; 70° 14'E) in the same area; also at Landi Kotal about 30 km, and at Jamrud, about 18 km west of Peshawar, and at Kund (33° 56'N, 72° 14'E) about 30 km east of Peshawar. Veins of talc are found in ultramafic rocks at Gach Inziakai and a number of other locations in Zhob District, Quetta Division. Near Chalt (36° 18'N; 74° 20'E) and at Nauseri north of Gilgit, talc is observed as constituent of sheared talcose schist, and in veins cutting slates (AHMAD 1969).

Vermiculite

Vermiculite is the name of a group of micaceous minerals with good bloating-, thermal insulation-, and fire proof-properties, dominantly used in various branches of the building industry. A substantial deposit of vermiculite is present in the Doki River area of the western Raskoh Range, about 21 km south of Dalbandin in Chagai District (Kalat Division). The deposit is a vermiculite schist formed by hydrothermal alteration of ultrabasic rocks. Small amounts of vermiculite were also observed in the associated biotite-pyroxene schist, hornblende schist, hornblende-pyroxenite and hornblendite. With reserves of about 11 mio t of coarse grained vermiculite with fair bloating capability (linear exfoliation 9 to 10 times of the original thickness after heating to 775 °C), the deposit was considered to be suitable for commercial exploitation (BAKR 1965, AHMAD 1969).

Vermiculite was also observed at Shinai Ghundai about 3.5 km northeast of Michni Fort (Mohmand Agency), northwest of Peshawar, and in the Arin Valley, about 56 km north of Saidu Sharif, Swat. Both deposits are small and apparently of no economic interest.

9.2 Stones and earths

Bentonite

The technical term bentonite is here used for clays of distinct plastic consistence with a montmorillonite content of at least 70 %. It is in general formed by redeposition of devitrified and decomposed, acid to intermediate tuff or other volcanic rocks.

HERON (1954), BOGUE & SCHMIDT (1961), BOGUE (1962), ALI et al. (1965) and CHAUDRY & ASHRAF (1977) reported on bentonite deposits from Bhimbar (Bhimber) (32° 58'N; 74° 05'E), Mirpur District. Here, as well as near Jammu (32° 42'N; 44° 72'E), the bentonite lenses and layers are as much as 1.20 m thick, of which 0.30 m is reported to be of "good quality". The beds appear in the upper part of the Siwalik Group and can be followed over distances of about 50 km (Bhimber), and 32 km near Jammu. These and other, similar deposits were also mentioned by SHAH (1977) from Qadipur-Bhilmor and Bhadrar in the central Salt Range, and from Rohtas-Dariala in the easternmost part of the Salt Range.

In the area of Qadipur and Bhadrar, more detailed investigations were discussed by SHAH (1980); some results are shown on Table 9.3.

Table 9.3. Data on bentonite from Qadipur and Bhadrar (after HERON 1954, AHMAD 1969, ASRARULLA 1972, RAZA & SHAH 1977).

	Formation	thickness	analyses (wt. %)
Qadipur area	lower part of Nagri Formation	lens-like up to 1.10 m	SiO_2 45.35; Al_2O_3 23.45; Fe_2O_3 0.81; CaO 1.75; loss on ignition 29.15
Bhadrar area	lower part of Nagri Formation	lens-like up to 0.70 m	SiO_2 49.85; Al_2O_3 23.02; Fe_2O_3 1.23; CaO 1.78; loss on ignition 22.98

Bloatable argillaceous raw materials

Large quantities of bloatable shale (Kuldana Formation; Eocene) and slate (Manki Formation; Precambrian) are exposed in parts of the Margala and the Attock-Cherat Ranges, in the area between Islamabad and Peshawar. According to PARKER (1968), KHAN & PARKER (1970) and HUSSAIN et al. (1983), detailed studies have shown the suitability of these raw materials for light-weight concrete aggregates. The shale and slate can be bloated successfully at 1,100 °C and 1,150 °C, respectively. The bloatable material is considerably lighter than the conventional aggregate; it is hard, highly cellular with a tough skin and of uniform structural strength. The deposits are easily accessible and workable, with practically unlimited reserves. Comparable deposits of bloatable argillaceous raw materials are expected at many other locations in western and northern Pakistan.

Brick raw materials

Clay, shale and loam are the main raw materials for the manufacture of bricks, clinkers, roofing and drain tiles, and similar ceramics. Such raw materials are found almost everywhere within the Neogene and Quaternary sediments of the Himalayas foreland and the Punjab further to the south, in Baluchistan, and in Sindh. Weathered slates are used for making bricks in the mountainous regions in the north and northwest of the country.

Building stones

Practically unlimited resources of building stones exist in Baluchistan, in the North West Frontier Province, and in the mountainous region of the Punjab; only a few, however, are found in Sindh. Many localities and sources of building stones have been cited by HERON (1954), AHMAD (1969), RAZA & IQBAL (1977).

In Baluchistan, good quality building stones can be obtained from:

- sub-Recent shelly limestone of the Makran Coast,
- Eocene Kirthar Formation (limestone),
- Paleocene Dunghan Formation (sandstone),
- Upper Cretaceous (Maestrichtian) Pab Sandstone,
- Upper Cretaceous Parh Limestone,
- diorites of the Ras Koh Range.

Similar rocks, and, in addition, slates, quartzites, granites and gneisses form abundant sources of building stones in the North West Frontier Province.

In the mountainous region of the Punjab, granites, quartzites, slates, as well as Tertiary sandstones in the forelands of the Himalayas yield good building stones. In the Salt Range, high quality materials are found in

- Early Cambrian Khewra Sandstone ("Purple Sandstone Series"),
- Cambrian Jutana Formation ("Magnesian Sandstone"),
- Late Permian Chhidru Formation (certain limestones and calcareous sandstones),
- Jurassic limestones and calcareous sandstones,
- Eocene nummulitic limestones.

In the province of Sindh, building stones are largely restricted to

- "Miliolite limestone", Mango Pir area,
- "Alveolina limestone", Jungshahi area,
- limestone of "upper Khairpur stage", Rohri and Sukkur areas,
- sandstone of "Nari stage", near Jungshahi, and about 25 km west of Karachi, Naka Pabni area,
- granite in the Nagar Parkar area, about 350 km east of Karachi; excellent quality, but long distance to main consumers.

Clay (kaolin, China clay, fire clay, fullers earth)

Kaolin (China clay) for manufacture of chinaware, whiteware and porcelains is present at Ahl (34° 34'N; 73° 09'E) in Hazara District of the North West Frontier Province (HERON 1954, ALI et al. 1964, KAZMI & SAFDAR 1963, FARUQI & QURESHI 1965, FARUQI et al. 1967, HUSSAIN & KHAN 1969, AHMAD 1969, ASHRAF et al. 1975, RAZA & IQBAL in SHAH 1977), at Shah Dheri (43° 52' 30"N; 72° 54'E), 23 km northwest of Saidu Sharif in Swat District (MOOSVI et al. 1974), and at Didwa Prodhora and Dhed Vero in the isolated Indian Shield area of Nagar Pakar in eastern Sindh (KAZMI & SAFDAR 1963). The deposits in the area of Ahl resulted from weathering in situ of foliated granite of Cretaceous age. One of the deposits near Battal (34° 35' 30"N; 73° 08'E) contains about 60,000 t of good quality kaolin.

The Shah Dheri kaolin was formed by the weathering of leucocratic quartz diorite. The clay content ranges between 16.5 % and 31 %; the total reserves are estimated at about 2.8 million t.

In the Nagar Pakar area, variable quality China clay has resulted from kaolinized feldspar in granite, with estimated reserves of more than 150,000 t.

HERON (1954) described a great number of deposits of **fire clay**, from Baluchistan (1), North West Frontier Province (6), Punjab (8), and Sindh (15). With additional information (AHMAD 1969), RAZA (in SHAH 1977) summarized the data.

Major deposits of fire clay, which are worked extensively, are found in the Salt Range and the Trans-Indus Range. They occur in the lower part of the Early Jurassic Datta Formation of terrestrial origin; also, in the lower parts of the Early Paleocene Hangu, and the Late Paleocene Patala Formations. Lenticular fire clay bodies overlying lignite beds in the Early Eocene Laki Formation were reported from Sonhari Dhand and Jhol Dhand in the Kirthar-Sulaiman region.

High-quality fire clays are formed by denudation of kaolinitic weathering products and their redeposition in lacustrine or paralic environments; commonly, they are associated with the formation of coal (STEIN, in BENDER 1986, p. 177). In Pakistan, all fire clays are apparently associated with strata containing coal beds or coaly material.

The term **"Fuller's Earth"** is understood here as a clay consisting of hydrous aluminium silicates including montmorillonite, with strong absorption properties and a high colloidal content. Many deposits are mentioned by HERON (1954), Hunting Survey Corp. (1960) and RAZA (1977), particularly, from the Lower Indus Basin, southern Sulaiman Range, in the Middle Eocene Khirtar Formation and Early Eocene Ghazij Group. Fuller's Earth was observed also in the Ghazij Group of the Lakhi Range, near Thano Bula Khan, and at the base of the Early Eocene Laki Formation between Sukkur and Kot Diji in the eastern Kirthar District.

Decoration stones (aragonite, travertine, marble, igneous rocks)

Aragonite and travertine form widespread deposits of marble, including high quality "onyx marble" in the Chagai District. Since ancient time, the attractively coloured stone is extensively quarried and used for ornamental purposes. The deposits were mentioned or described by HERON (1954), AHMED, W. (1960), AHMED, M. (1965) and AHMED, W. (1965). Important localities are about 56 km northwest and about 96 km ENE of

Nokkundi (Nok Kundi, 28° 48' 30"N; 62° 05' 50"E). These hot-spring deposits are associated with the Neogene through sub-Recent volcanism in this part of Baluchistan.

Travertine was formed, like aragonite, by precipitation of calcium carbonate in thermal or mineralized water. Subrecent or older travertine is diagenetically altered and solidified enough for cutting and using it as decoration or building stone. AHMED (1965), AHMAD (1969, 1981), HUNDAL & GAUHAR (1974), RAZA (1977), SHAH (1980) and BILGRAMI (1982) reported on numerous travertine deposits from the zone of Pleistocene to sub-Recent volcanism in Baluchistan between latitudes 62°E to 65°E. Here, thick bodies and layers of travertine are interbedded with volcanic rocks, deposited on an irregular topography.

Marble deposits are known from the northern and northwestern mountainous region (HERON 1954, ASRARULLAH 1963, AHMAD 1969, SHAH & SIDDIQUI 1976, RAZA 1977, ASRARULLAH & HUSSAIN 1985).

Pure white, fine-sachharoidal marble is present in huge quantities associated with phyllite and semi-schistose pelitic rocks, in the Mullagori area near Shahid Mena (34° 09'N; 71° 17'E) and along Kambela Khwar, in the North West Frontier Province. It forms part of the Carboniferous-Permian Khyber Limestone Formation. The Shahid Mena marble consists dominantly of white "Carrara-quality" marble, the Kambela Khwar deposits vary in colour and purity.

Very large quantities of marble are also observed at Maneri (34° 08'N; 72° 28'E), and at the Ghundai Tarako Hill (34° 13'N; 72° 28'E) in the northern Peshawar Plain. According to STAUFFER (1968), these marbles developed in the Silurian-Devonian reef complex of the Nowshera Formation.

Marble deposits were reported also from 8 km south of Saidu Sharif (34° 53' 30"N; 72° 54' 00"E), in the "Alpurai marble-amphibolite unit" (possibly correlates with the Lower Paleozoic section of the Nowshera Formation), and 4 km east of Karora, in the Karora Group.

Various **igneous rocks** apparently suitable for the manufacture of decoration and ornamental stones exist at many places, such as diorites in the Ras Koh Range (Baluchistan), and granites in the Nagar Pakar area (Sindh). None of them were, however, investigated yet with regard to their suitability.

Dolomite

Extensive deposits of dolomite were reported from the
- upper part of the Salt Range Formation,
- Cambrian Jutana and Khisor Formations,
- Permian Khyber and Devonian Shagai Limestone Formations,
- Triassic Kingriali Formation,
- Middle Jurassic Samana Suk and Takatu Limestone Formations, and the
- Early Eocene Laki Formation.

HERON (1954) and AKHTAR et al. (1970) described white-grey crystalline dolomite (marble) within the Paleozoic sequence at Ghundai Tarako, Jarl (34° 09'N; 73° 05'E) and Sobran Gali (34° 10'N; 73° 09'E), in the North West Frontier Province. The

Table 9.4. Major limestone resources (after HERON 1954, AHMAD 1969, ASRARULLA 1972, RAZA & SHAH 1977).

Areas	Formation	
Hyderabad Division		
Jungshahi-Kotri Ganjo Takar near Hyderabad	Early Eocene Laki Fm.	90 % $CaCO_3$ cement qualities
Karachi Division		
Murli Hill 16 km NE Karachi	Early to Middle Miocene Gaj Fm.	58 % to 92 % $CaCO_3$, cement qual.
Mangho Pir 15 km NW Karachi	Oligocene Nari Fm. Miocene Gaj Fm.	cement qualities
Khairpur Division		
east of Khairpur and Rohri	Eocene Kirthar Fm.	53.6 % – 53.9 % CaO, cement qual.
Multan Division		
Zindapir area	Eocene	43 % – 52 % CaO, 1 % – 3 % Al_2O_3
Quetta and Kalat Divisions	Jurassic, Cretaceous, Paleocene, Eocene	in parts cement qualities
Dera Imail Khan Division		
Pezu (32°19’N; 70°44’E)	Jurassic	55.5 % CaO
Moghalkot (31°55’N; 69°05’E)	Paleocene	51.4 % CaO
Sargodha and Rawalpindi Divisions		
Cis-Indus Salt Range	Middle Permian Wargal Limest. Fm. (between Kagha 32°31’N; 72°21’E, and Daud Khel),	54 % – 55 % CaO
	late Jurassic (Khairabad, 32°53’N; 71°36’E);	53 % – 54 % CaO
	Early Eocene Sakesar Limest. Fm. (Beth Kas, 32°52’N; 73°27’E, to Sakesar area)	49.5 % – 54.5 % CaO, in parts cement quality
Trans-Indus Salt Range	same Formation	similar in chemical composition
Potwar Plateau	Jurassic, Eocene (Tarki, 33°04’N; 73°25’E; near Wah; Margala Hills)	at Wah 98 % $CaCO_3$; elsewhere 43 % – 55 % CaO; in parts cement qualities
Peshawar Division		
Khyber Agency-Nowshera	Silurian-Devonian Shagai Limestone and Khyber Carbonates	
Kohat area	Jurassic	43.5 % CaO, 8.8 % MgO, not suitable for the manufacture of cement
	Cretaceous	≈ 50 % CaO, 1.7 % Al_2O_3, 1.6 % MgO
	Paleocene	≈ 51 % CaO, 1.4 % Al_2O_3, 1.5 % MgO
	Eocene	≈ 53 % CaO, 0.94 % Al_2O_3, 0.9 % MgO

MgO-contents of these marbles range between 19 % and 21 %, the CaO-contents between 31 % and 33 %.

RAZA & IQBAL (1977) reported good quality dolomite about 80 m thick with 900 million t of estimated reserves in the Triassic Kingriali Formation, in the Surghar Range. Near Quetta, dolomite as much as 80 m thick is present at the base of the Jurassic Takatu Limestone, in the Chiltan Range. Here, about 250 million t of reserves were estimated for a strike extension of 5 km, with an average MgO-content of 20 %, and a CaO-content of 32 %. Large deposits exist also in the upper part of the Permian Khyber Formation and in the Devonian Shagai Limestone Formation, in the Khyber Agency. Representative contents are 20.1 % MgO and 30.1 % CaO.

Limestone

Practically unlimited reserves of limestone suitable for almost all industrial and agricultural purposes are extensively exposed in the south, west and north of Pakistan. Only some of the major resources are listed in Table 9.4 (HERON 1954, AHMAD 1969, ASRARULLAH 1972, RAZA & SHAH 1977).

Sand, gravel, crushed stones

Sand and gravel for the building industry and for infrastructural works are widespread with practically unlimited reserves (HERON 1954, RAZA & IQBAL 1977).

Gravels of suitable qualifications for all these purposes are present in the stream beds and form parts of the terraces in the foot hill zones of the entire Indus Basin.

Sand adequate for various uses is extensively deposited throughout the Indus drainage system and along the coastal beaches. Because of the easy availability of these unconsolidated raw materials, the production of crushed stone or sand from consolidated rocks is limited.

9.3 Salts

Potash salts

Potash salts at Khewra (Salt Range, Jhelum District, Punjab) were first mentioned by WARTH (1873), and later examined, among others, by CHRISTIE (1914), STUART (1919), HERON (1954), BHATTY et al. (1966), JONES & ASRARULLAH (1968), JONES (1970), ALAM & ASRARULLAH (1973) and SAWAR & ASRARULLAH (1973).

Potassium salts are present in the Billianwala Salt Marl Member of the Salt Range Formation, which consists of ferruginous red marl with thick beds of rock salt and layers of salt marl. This Formation is more than 650 m thick; it rests on Precambrian igneous and metamorphic rocks of the Indian Shield and is thought to be of "Infra-Cambrian" or Late Proterozoic age (SHAH 1980). The minerals identified in the potash ore are halite, sylvite, kainite, langbeinite, kieserite, polyhalite, mirabilite, glauberite, silicate and clay minerals. The potash layers, streaks, flat lenses or lenticles are as much as 4 m thick and are in 7 different "Salt Marl Beds" which separate various thick rock salt layers in the Khewra (32° 39'N; 71° 45'E) salt mines. The potash deposits have a lateral (east-west) extent between about 240 m and 400 m, and contain an average of 7.83 % K_2O; the total proved reserves of potash containing 9.4 % K are 124,850 t (ALAM & ASRARULLAH 1972). Although some potash was produced, the low grade, thin layers and relatively small reserves made it impossible to achieve economic exploitation.

The Salt Range Formation shows a rhythmic deposition: The potassium salts were, as a result of ongoing evaporation of the brines, repeatedly precipitated at the end of each period of rock salt sedimentation. This happened seven times as observed in the Khewra mines. As ALAM & ASRARULLAH (1972) pointed out, the Khewra deposits might represent a near-shore potassium-sulphate facies, whereas further to the northwest (Dhariala oil exploration well, 15 km northwest of Khewra), about 2,150 m of the Salt Range Formation was penetrated), a sylvite-rich facies might have been developed more to the center of the evaporite basin.

Rock salt

Since the middle of the last century, many observers have given accounts on rock salt deposits in Pakistan, among others FLEMING (1853 a, 1853 b), THEOBALD (1854), WYNNE (1878), MIDDLEMISS (1891), CHRISTIE (1914), GEE (1934, 1935), HERON (1954), AHMAD (1969), ASRARULLAH (1967, 1972), RAZA & IQBAL (1977), SHAH (1980), AHMED (1981), and BILGRAMI (1982).

Major deposits of rock salt are present in the Salt Range Formation (Upper Proterozoic, "Infracambrian"), and in the Bahadur Khel Formation (Early Eocene). The rock salt production from these sources ranges between 330,000 t and 610,000 t annually.

The lower member of the Salt Range Formation (Billianwala Salt Marl Member; ASRARULLAH 1967) rests with dolomite and gypsum on metamorphic Precambrian rocks (see Chapter 3.21) and granite (correlates with the Nagar Paker granite having an age of 700 mio years; CRAWFORD 1969, SHAH 1980). Parts of the evaporite-bearing rock sequences are exposed (Fig. 3.3), along the southern escarpment of the Salt Range with salt mines at Khewra (32° 39'N; 71° 45'E), Warcha (32° 29'N; 71° 59'E) and Kalabagh (32° 55'N; 71° 32'E).

At Khewra, a lower complex with three salt beds as much as 25 m thick (exceptionally up to 90 m) are mined within the lower member of the Salt Range Formation. This "Buggy complex" of salt beds with intercalated red marl is separated by a sequence of marl, salt-marl and thin salt beds about 35 m thick from the underlying "Pharwala complex", which contains four exploitable salt beds between 10 m and 25 m thick. The estimated reserves at Khewra are in excess of 600 million tons.

At Warcha, five salt beds are exploited having a total thickness of 30 m to 50 m. They are separated by marl ranging in thickness from a few centimeters to 25 m. The estimated reserves of salt are more than 2 million t. Some individual beds as much as 35 m thick are mined at Kalabagh, where the estimated reserves exceed 1 million t.

The evaporites of the Salt Range Formation were apparently formed during the latest Precambrian and/or Early Cambrian, when more than 1,600 m-thick evaporite-bearing sequences were deposited in a shallow-marine environment, locally and periodically influenced by restrictions of the connection between marginal basins and the open sea. Not only vast areas in Pakistan but also in eastern and central Iran underwent a similar palaeogeographic evolution, where the time equivalents of at least parts of the Hormuz Salt Formation (HUCKRIEDE et al., in STÖCKLIN 1972) show a comparable lithologic development.

The evaporite-bearing sequence of Early Eocene age is locally exposed over an area of more than 5,200 km^2 in the Kohat District (Jatta-Bahadur, Khel-Karak). Massive to bedded salt as much as 100 m thick is quarried in the Bahadur Khel Salt Formation. It is in general white, in places dark grey or dark grey-bituminous; the upper contact is conformable with the Early Eocene Jatta Gypsum Formation, the lower contact is gradational with the Panoba Shale, also of Early Eocene age. At Bahadur Khel, the salt formation was penetrated by drilling for about 500 m without reaching the base.

Salt ("solar salt" from brines and salt lakes) is produced in the coastal areas at many places of Makran and Las Bela, and in a seasonal lake in the centre of a large desert depression near Gwalishtap (Hamun-i-Mashkel; 28° 20'N; 62° 45'E) in Chagai District. Salt is also recovered from sea water by solar evaporation and fractional crystallisation at Mauripur, about 13 km west of Karachi; it is further worked extensively at Landi, near Dabheji, on the Moach Plain, and from salt lakes at Khipro Nawabshah, as well as at Saran Dipla, Thar Parkar (all localities in Sindh). The production of solar salt is in the order of 125,000 t annually.

9.4 Gemstones

(ALI H. KAZMI)

Gemstones have been intimately linked with the ancient history of Pakistan; since the early civilizations of Mohenjodaro, Harrapa, Gandhara and Taxila, they have been used as objects of adornment, symbols of power and glory, and as exchange in trade. Cutting and polishing of gemstones by traditional methods is an old craft in Pakistan as evidenced by archaeological remains of these cultures. During the early years of Pakistan, the gem resources in the country remained unexplored. However, beginning from 1958, a series of discoveries of gemstones have been made and, during the last decade, Pakistan has become a major supplier of precious and semi-precious stones (Table 9.5).

Table 9.5. Gemstones in Pakistan (mineable deposits marked by asterisk).

Actinolite
*Agate
*Aquamarine
Azurite
*Emerald
Epidote
*Feldspar (moonstone)
*Garnet
*Onyx marble
*Pargasite
*Pink topaz
*Quartz
*Rodingite
*Ruby
Rutile
*Serpentinite
*Spinel
*Topaz
*Tourmaline
Turquoise
Vesuvianite

From the metallogenic and geological standpoint the gemstones of Pakistan may be placed under the following four main categories (KAZMI & O'DONOGHUE 1990):

- **suture-associated:**
  actinolite, emerald, epidote, pargasite, rodingite, ruby, serpentinite, spinel, vesuvianite;
- **pegmatite-associated:**
  aquamarine, emerald, feldspar (moonstone), garnet, quartz, topaz, tourmaline;
- **gemstones in hydrothermal veins:**
  azurite, pink topaz, rutile, zircon;
- **miscellaneous gemstones:**
  agate, green grossular garnet (tsavolite), hessonite garnet, onyx marble, turquoise. These include some of secondary occurrences of agate, and showings of various gemstones which have not yet been worked or investigated in detail.

Following is a brief description of the gemstones arranged in order of their geologic environment and economic significance.

Suture-associated gemstones occur along crustal suture zones such as the Indus suture zone marked by the Main Mantle Thrust (MMT) and the Karakoram suture zone characterized by the Main Karakorum Thrust (MKT). They are largely of pneumatolytic, hydrothermal, or metamorphic-cum-metasomatic origin (KAZMI et al. 1984, 1986; KAZMI & SNEE 1989; LAWRENCE et al. 1989).

Emeralds, except for the Khaltaro deposits (35° 57’ 30”N; 74° 41’ 40”E in the Gilgit area) which are in pegmatite veins, are associated with the ophiolitic mélange of the Indus suture zone (KAZMI & SNEE 1989). This zone is composed of a complex set of distinguishable mélange units (Fig. 9.2) separated by thrust faults (KAZMI et al. 1984). In the suture zone the emeralds are largely in talc-chlorite schist, commonly associated with stockworks of quartz and calcite, calcite veins or small lenses of quartz (Figs. 9.2, 9.3, 9.4).

Emeralds are found at Dandao Kandao (34° 27’ 30”N; 71° 32’ 20”E), Bucha (34° 25’ 45”N; 71° 34’ 10”E), Nawe Dand (34° 26’ 30”N; 71° 35’ 15”E), Gandao (34° 26’ 45”N; 71° 39’ 10”E), Kot (34° 29’ 15”N; 71° 43’ 2”E), and Mor Darra in Mohmand Agency;

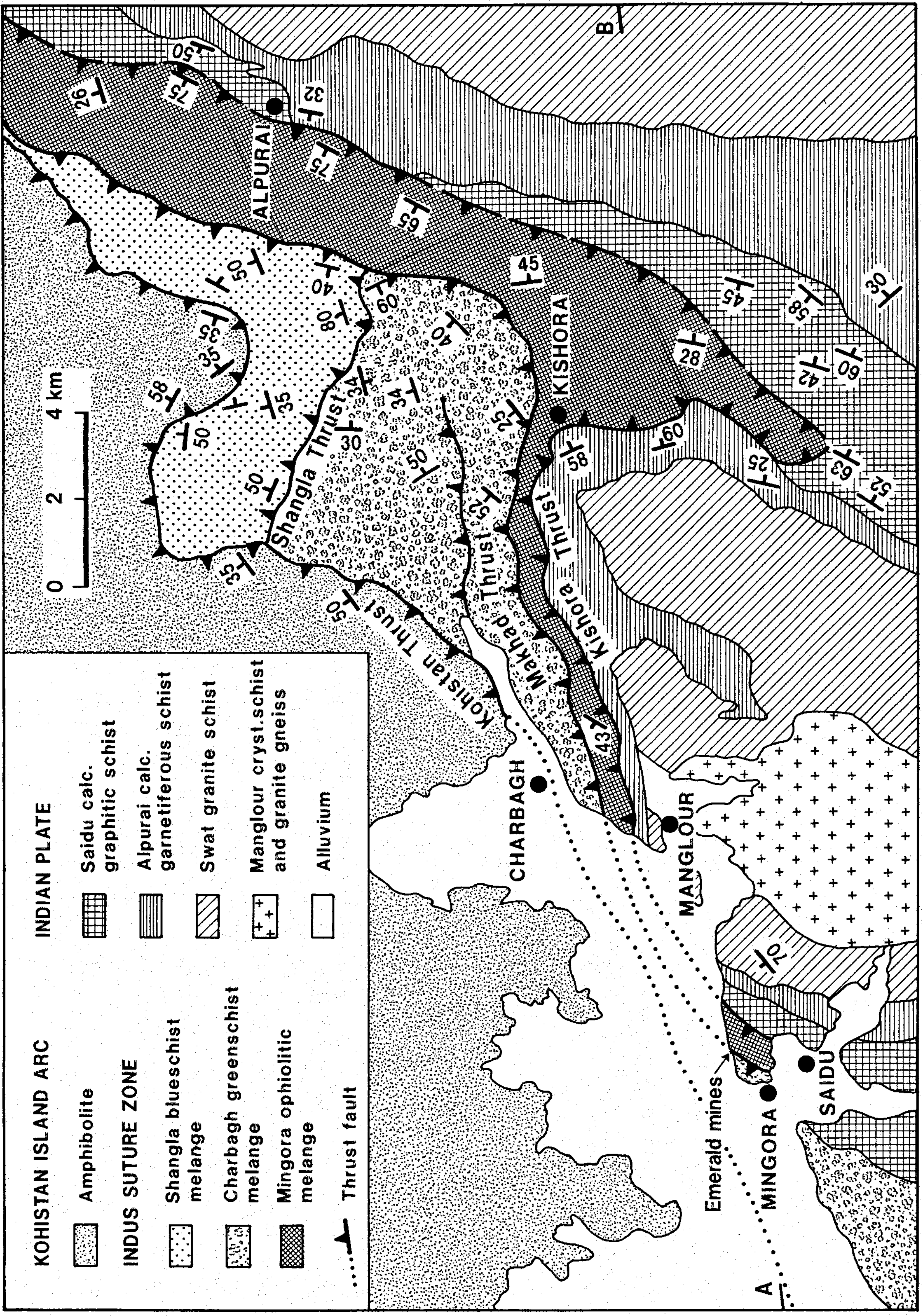


Fig. 9.2. Geological map of Mingora – Alpurai area (after KAZMI et al. 1987).

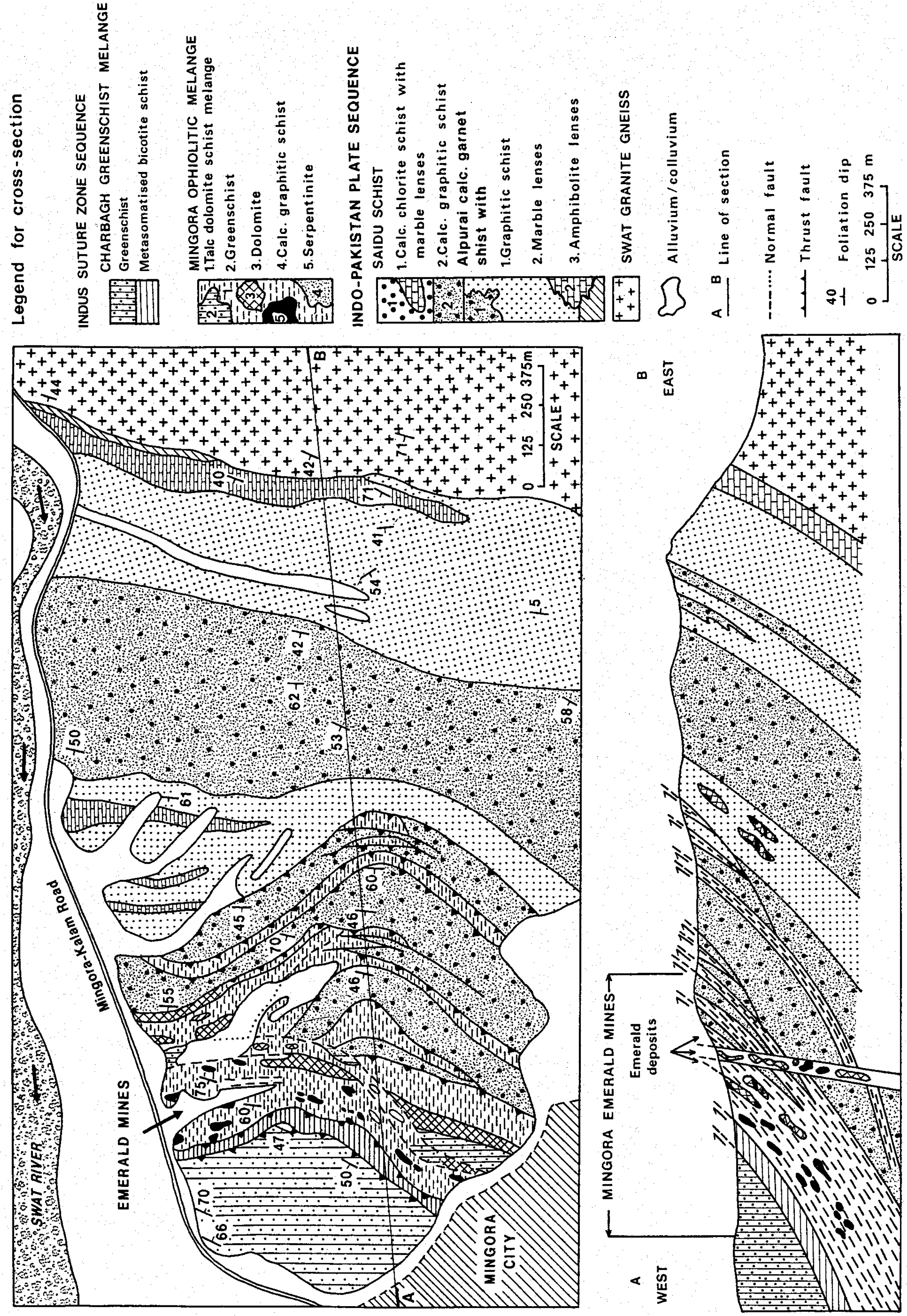


Fig. 9.3. Geological map and cross-section of the Mingora emerald area (after KAZMI et al. 1984).

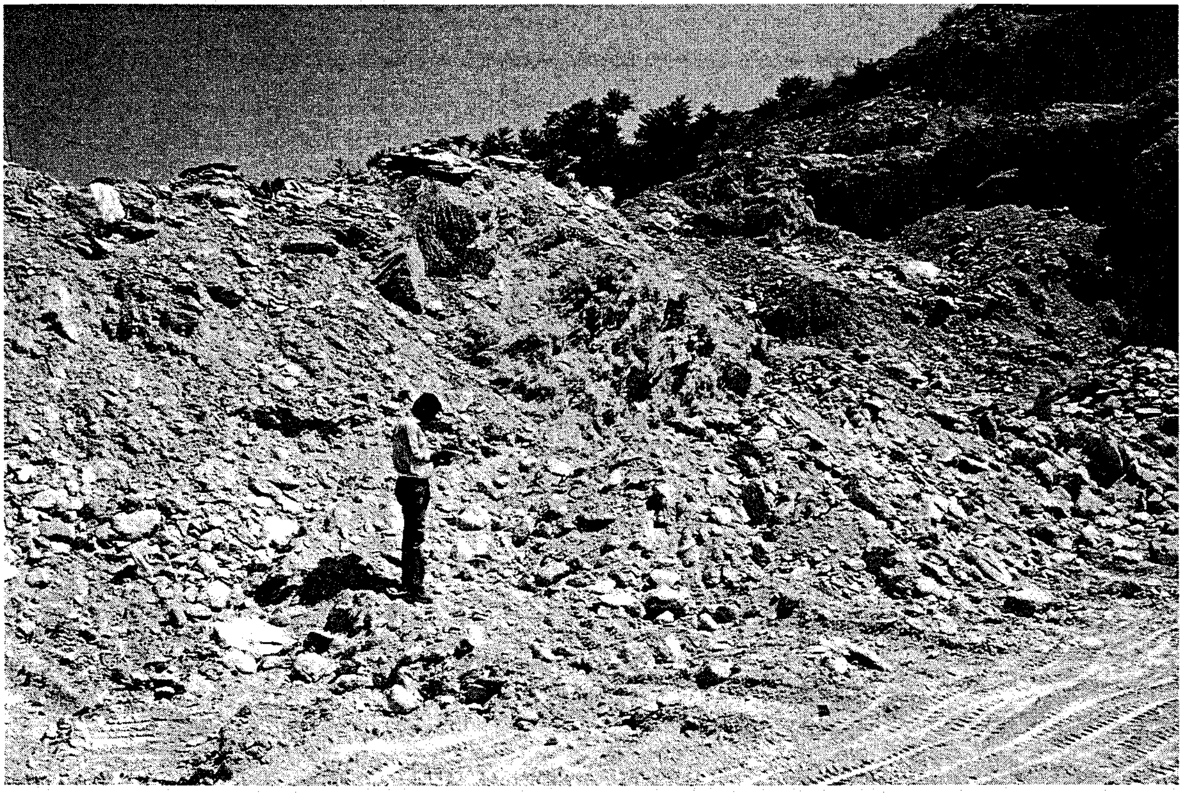


Fig. 9.4. Emerald mine at Mingora (Photo: F. BENDER).

Arang Barang (34° 36' 20"N; 71° 34' 10"E) in Bajaur Agency; Mingora (34° 47' 5"N; 72° 22' 2"E), Charbagh (34° 50' 5"N; 72°26' 30"E), Makhad (34° 50' 10"N; 72° 32' 15"E) and Gujarkili (34° 46' 45"N; 72° 37' 30"E) in Swat District.

The Swat deposits are producing excellent quality material, described by GÜBELIN (1968, 1982, 1983 a) as carrying some of the finest emeralds in the world. These stones have become well known for their brilliant, medium to deep green colour as well as for their unique transparency and are comparable to the finest Colombian specimens from Muzo (GÜBELIN 1968).

The emeralds from the Mohmand Agency are yellowish green to bluish green and the colour is less intense than that of Swat material. The host rocks are talc-carbonate schist, quartz veins and dolomite. The Gandao stones are actually green beryls and not emeralds (KAZMI & SNEE 1989) since the colouring agent is not chromium but vanadium and possibly iron (HAMMARSTROM 1989).

Epidote has a characteristic yellow-green colour which can vary to a deep olive green. Its refractive index is 1.73 - 1.76 for any transparent material which may be used as a gemstone. In Pakistan most of the gem grade deposits of epidote occur in hydrothermal veins and as alteration products in gabbro and greenstone of the melange complex. These deposits are located in the Indus suture zone close to Bunji (35° 39' 55"N; 74° 37' 2"E) in Gilgit Division; near Kot (34° 29' 15"N; 71° 43' 2"E), Pranghar (34° 26' 55"N; 71° 37' 10"E), and Bucha (34° 25' 45"N; 71° 34' 10"E) in Malakand and Mohmand Agencies and at several localities in the Swat District.

Actinolite is one of the amphibole group of minerals and is in gem trade; it includes the jade mineral nephrite. It has an attractive green colour, is easy to cleave but difficult to cut and polish. Gem trade transparent crystals of actinolite of exquisite deep green colour are found in metamorphosed greenstone and in talc-chlorite-actinolite schist in the suture zone near Bunji (35° 39' 55"N; 74° 37' 2"E) and Chilas (35° 25' 2"N; 74° 5' 20"E) in the Gilgit Division, and in the Charbagh-Alpurai area of the Swat District.

Rodingite is a low grade metamorphic rock largely comprised of hydrous calcium-aluminium silicates such as hydrogrossular garnet, clinozoisite, zoisite and vesuvianite. It has an attractive high to medium green colour. Some stones are of a light cream colour mottled with specks of green. It is mainly used for gem carving and for making beads and cabochons. It was also used for making artefacts. The ultramafic complex in the Malakand District near Dargai contains large and extensive layers and lenses of rodingite (QAISER et al. 1970, 1972).

Vesuvianite is a complex calcium-aluminium silicate having chemical and structural similarities with grossular garnet. One variety known as californite consists of a mixture of grossular and vesuvianite and resembles in appearance the jade minerals. Exquisite pistachio green tetragonal crystals of vesuvianite have been found near Muslimbagh in Zhob District in calcite veins in the ultramafic complex. Though the original deposit was soon exhausted, crystals of vesuvianite have reappeared in the Quetta market suggesting that the local tribesmen may have now discovered a new source. A massive green rock composed of cryptocrystalline grains of vesuvianite forms large lenticular bodies in serpentinites west of Dargai (34° 29' 10"N; 71° 54' 25"E) in Malakand District, and northwest of Pranghar (34° 26' 25"N; 71° 37' 10"E) in Mohmand Agency. It is being used as a decorative stone for carving and for making cabochons.

Serpentinite has a relatively low hardness (3.5 – 5) but stones of attractive green colour provide excellent material for carving. Some of it is being cut into cabachons for inexpensive jewellery and used as decorative stone. Extensive deposits of serpentinite are associated with the melange/ophiolitic belt in the Gilgit area and in the Swat, Malakand, Mohmand, Parachinar, Waziristan, Zhob and Lasbela areas.

Ruby is found in the marbles in the Northern Areas and in Azad Kashmir. These marbles are known to contain substantial quantities of ruby and sapphire. Ruby also occurs in a 30 km long belt of amphibolites extending from Timargarah (34° 51' 30"N; 71° 52' 45"E) to Kabal (34° 46' 10"N; 72° 16' 30"E) in the North West Frontier Province (N W F P). The ruby deposits occur also in a dolomitic marble belt extending from the Hunza Valley to Ishkoman for more than 100 km, close to the Main Karakorum Thrust (MKT). Presently most of the mining is confined to about 13 mining sites spread over a length of 15 km in the Hunza Valley. The Hunza ruby crystals are commonly well formed and are pink to fine red in colour. Calcite crystals are often found in the stones and cause opacity. The Hunza rubies contain inclusions of calcite, dolomite, phlogopite, rutile, pyrrhotite, goethite, pyrite, chlorite, margerite, apatite and spinel (OKRUSCH et al. 1976, GÜBELIN 1982). OKRUSCH et al. (1976) assumed, on the basis of experimental data that, during the regional metamorphism, temperatures of about 600 °C – 620 °C and a water vapure pressure of about 6 kb were realized in the Hunza area. The gas phase must have contained roughly 20 mole-% of CO_2. Thus the fluid pressure may have reached about 7 kb. GÜBELIN (1983 a) pointed out the striking geological, petrographical and gemmological similarity with the famous ruby deposits of Mogok im Myanma (Burma; BRINCKMANN in BENDER 1983). Based on detailed gemmological studies he defined "pidgeon blood red" ruby of highest quality.

In addition to the rubies the marble host rock contains the following mineral association: Spinel, pargasite, margarite, phlogopite, chlorite, graphite, pyrite, rutile, dolomite, sphene, apatite, tourmaline, plagioclase, pyrrhotite, quartz, calcite and goethite (OKRUSCH et al. 1976, GÜBELIN 1982, KAZMI et al. 1990). This mineral association is, however, less diagnostic for the Hunza ruby than its internal parageneses. Its main distinguishing features are: Turbidity, numerous fine cracks, parting planes, polysynthetic twinning, irregular swirl marks and mineral inclusions.

Spinel with its ruby red colour is closely associated with Hunza ruby deposits. The Hunza spinels occur in a wide variety of colours ranging from brown, red, plum red, violet to blue. These colour variations are mainly a result of slight changes in their chemical composition. For example the red colour is largely related to the presence of chromium, whereas the bluish and plum-coloured varieties owe their colour to the presence of iron (KAZMI et al. 1990). The Hunza spinels are larger than those customarily found in Burma and are far more attractive. They are commonly euhedral, showing recognizable crystal forms.

Pargasite is a monoclinic amphibole. Exquisite deep pistachio green crystals of pargasite are found in the metamorphosed crystalline marbles along with ruby and spinel in the Hunza Valley. The stones are transluscent to opaque and are commonly fashioned into beautiful cabochons. Locally they are sold as "Hunza emeralds".

Pegmatite-associated gemstones are found in the Northern Areas where extensive pegmatites have formed consequent to the synorogenic emplacement of granitic batholiths. The pegmatites are largely concentrated in the Gilgit-Skardu region (Nanga Parbat, Haramosh and Karakorum Ranges), in the Indus Kohistan area, and in Chitral (Hindukush Range). Some of these pegmatites contain gemstones and mineral specimens ranging from beryl, aquamarine, topaz, green and multicoloured tourmaline, garnet, fluorite, mirocline, orthoclase, montmorillonite, muscovite, and less commonly, cassiterite, fluorapatite, hambergite, hydroxyl-herderite, manganotantalite, and zircon (KAZMI et al. 1985). The gemstones that are more significant from the point of exploitation are briefly described below:

Aquamarine, the blue variety of beryl, is found as euhedral crystals in the gem pegmatites of Dusso (35° 42' 55"N; 75° 29' 5"E), Tisgtung (35° 43' 2"N; 75° 28' 15"E), Bulechi (35° 41' 30"N; 74° 48' 55"E), Shingus (35° 43' 50"N; 74° 48' 5"E), Iskere (35° 54' 10"N; 74° 45' 30"E) and Khaltaro (35° 57' 30"N; 74° 41' 40"E) in the Gilgit-Skardu region, and in the Gabor-o-Bakh (36° 5' 1"N; 71° 21' 50"E) region of Chitral. The Gilgit-Skardu aquamarines are rather lighter in colour, whereas the most intense inky blue aquamarines are found in Chitral. Goshenite and morganite (varieties of beryl) are also commonly found in these pegmatites.

Apart from their value as gemstone, the well-formed aquamarine crystals associated with other pegmatite minerals provide highly prized collector's specimens and museum pieces.

Tourmaline minerals include several distinct species, and many of these provide specimens of gem quality. The gem varieties include rubellite, dravite, elbaite and liddicoatite (KAZMI & O'DONOGHUE 1990). Their range of colours exceeds that shown by any other gem mineral. Deposits of gem quality tourmaline are found in the pegmatites in the Haramosh Range near Gilgit (pink, blue and green varieties). The best known deposits are in the Stak Nala (between Gilgit and Skardu). This locality is now famous for bi-colour and tri-colour tourmalines. The colours are commonly dark green or black at the base with the terminations being grass green, pink or blue. The crystals are euhedral with prismatic terminations and are commonly 4 cm to 6 cm or more in length.

Gem trade tourmalines also occur at Bulechi and Shingus (Gilgit Division). Indicolite (blue tourmaline) is found in the gem pegmatites of Garm Chasma (Chitral). Recently a new tourmaline locality has been discovered in the Neelam Valley of Azad Kashmir from where some of the best and fairly large specimens of bi-colour and tri-colour tourmalines have been found.

Topaz is a popular gem and occurs commonly as colourless, light-yellow or blue crystals. The yellow variety resembles citrine (yellow quartz), but it is incomparably more beautiful and attractive mainly due to its higher refractive index (1.62), hardness (8) and specific gravity (3.5 - 3.6). Topaz found in the gem pegmatites ranges from colourless to slightly yellowish brown to a deeper sherry-colour; large, perfectly euhedral crystals are quite common. They mostly appear in a microcline-quartz-muscovite matrix. Topaz bearing pegmatites are largely found at Bulechi (35° 41' 30"N; 74° 48' 55"E) and Shingus (35° 43' 50"N; 74° 48' 5"E) in Gilgit area, and at Niyit Bruk (35° 43' 55"N; 75° 31' 5"E) and Gone (35° 41' 58"N; 75° 31' 30"E) near Dusso in the Skardu area.

Feldspar is one of the commonest of minerals in the earth's crust but not all of the many feldspar varieties are of an ornamental nature. Moonstone is the best known gem variety. Sanidine, peristerite and perthite are also used as decorative stones. Beautiful euhedral crystals of microline and plagioclase feldspar are found in abundance in the gem pegmatites of Skardu, Gilgit and Chitral. Deposits of moonstone occur in the gem pegmatites of Bulechi and Shingus in the Gilgit area.

Quartz is a common mineral, but also includes a wide variety of ornamental types. The ornamental varities can be crystalline, such as amethyst and citrine, or cryptocrystalline, such as agate, chrysoprase, chalcedony and cornelian. Clear and well formed crystals of quartz occur in gem pegmatites in Skardu, Gilgit and Chitral areas, and in Azad Kashmir. Smoky quartz is also commonly found in these areas. Rose quartz is abundant in Dusso pegmatites near Skardu. Agate and chalcedony are found near Nagar Parkar (24° 10' 58"N; 70° 23' 2"E) Sindh, while jasper occurs in Lasbela area (Baluchistan).

Gemstones in hydrothermal veins are pink topaz, zircon, rutile and azurite. The last three were observed only as scattered showings. Only the pink topaz, which is perhaps the foremost gemstone of Pakistan, is being mined and is briefly described below:

Pink topaz ranging in colour from deep red, orange-rose or cyclamin colours is unique to the Katlang (34° 21' 20"N; 72° 4' 1"E) topaz deposit. In fact, this is the only known naturally deep red or deep pink coloured topaz in the world. The colour of these Katlang stones ranges from colourless to very pale beige to light brown, from very pale to deep pink to bright red. Even violet-coloured crystals have been found (GÜBELIN et al. 1986, KAZMI & O'DONOGHUE 1990). The Katlang topaz deposit is located in the Ghundao Hillock 4 km north of the town of Katlang, about 20 km north of the city of Mardan, 60 km NE of Peshawar. The Ghundao Hillock is formed as a small anticlinorium with fold axes trending east-west. It consists of grey, thin- to thick-bedded Paleozoic (?) crystalline limestones which have been dragfolded and extensively faulted. The limestones contain extensive stockworks of calcite and quartz veins which host the topaz mineralization. The gem-bearing veins are mostly along a series of parallel, normal and reverse faults near the crest of the tightly-folded anticlines.

Among the miscellaneous gemstones, agate is one of the cryptocrystalline varieties of quartz; other varieties such as jasper, chalcedony, carnelian, and onyx are based on colours and patterns. Agate is the variety which usually contains coloured layers or bands, flat or concentric. Nodules of agate are found in cavity fillings in basaltic and andesitic lavas and are widely distributed in the Nagar Parkar area (Sindh) and in Dir Kohistan (N W F P).

Garnet includes many distinct mineral species, at least six of which have gem potential. The garnets present a wide range of colours ranging from yellow, brown, red to green. Gem quality almandine (red) garnet is found in Chitral District, red spessartine garnet in the gem pegmatites of Dusso (35° 42' 55"N; 75° 29' 5"E) and Shingus (35° 43' 50"N; 74° 48' 5"E), in the Northern Areas. Tsavolite or green grossular appears in graphitic schists in the Jambil area of Swat, near Kot in Malakand District and near Targhao in Bajaur Agency. The Jambil garnets have provided exquistite facetted gems, whereas the Targhao garnets make good cabochones. Near Targhao (Bajaur Agency) beautiful honey yellow euhedral crystals of hessonite garnet are found in mineable quantities in quartz-mica schist.

Turquoise has been found in the Chagai Hills, in Chagai District of Baluchistan. It is expected that further investigations may prove this find to be an economically exploitable deposits.

Onyx marble in the Chagai District of Baluchistan constitutes the largest deposit of decorative stones in Pakistan. The marble is being mined in the form of huge blocks weighing several tons. It has various shades of light green, mauve green, brown and light yellowish green; the most valuable is a translucent green colour. Brown, black and white banding in the green matrix gives it a most attractive appearance.

Mineral specimens are also of growing interest in Pakistan. The attraction of mineral specimens as distinct from facetted stones lies in their form and colour. Mineral specimens do not have to be of gem quality, though the few gem crystals that escape cutting are admittedly most beautiful. In recent years a large and a flourishing market for good mineral specimens as collector's items has developed world wide. The pegmatites of the Northern Areas have yielded excellent light pink crystals of **fluorapatite**, green **fluorite, spessartine, hambergite**, green **microcline, aquamarine, tourmaline, topaz,** and **garnet**. Exquisite mineral specimens of **ruby, spinel** and **paragasite** are found in the

Hunza Valley. Beautiful **pyrite, malachite** and **azurite** specimens can be collected near Gilgit. Attractive violet coloured **fluorite** crystals occur in the Koh-e-Dilband fluorite mines (29° 30'N; 66° 55'E) in Kalat District. The Indus suture zone between Chilas and Mohmand Agency abounds with **epidote, actinolite** and **rodingite**; less commonly are **zircon** and **rutile**. Some of the rarest and best pink topaz specimens are found in the Katlang topaz mine.

It would thus be seen that Pakistan is virtually a paradise, not only for gemstones and gem connoiseurs, but also for rock-hounds and collector's of mineral specimens.

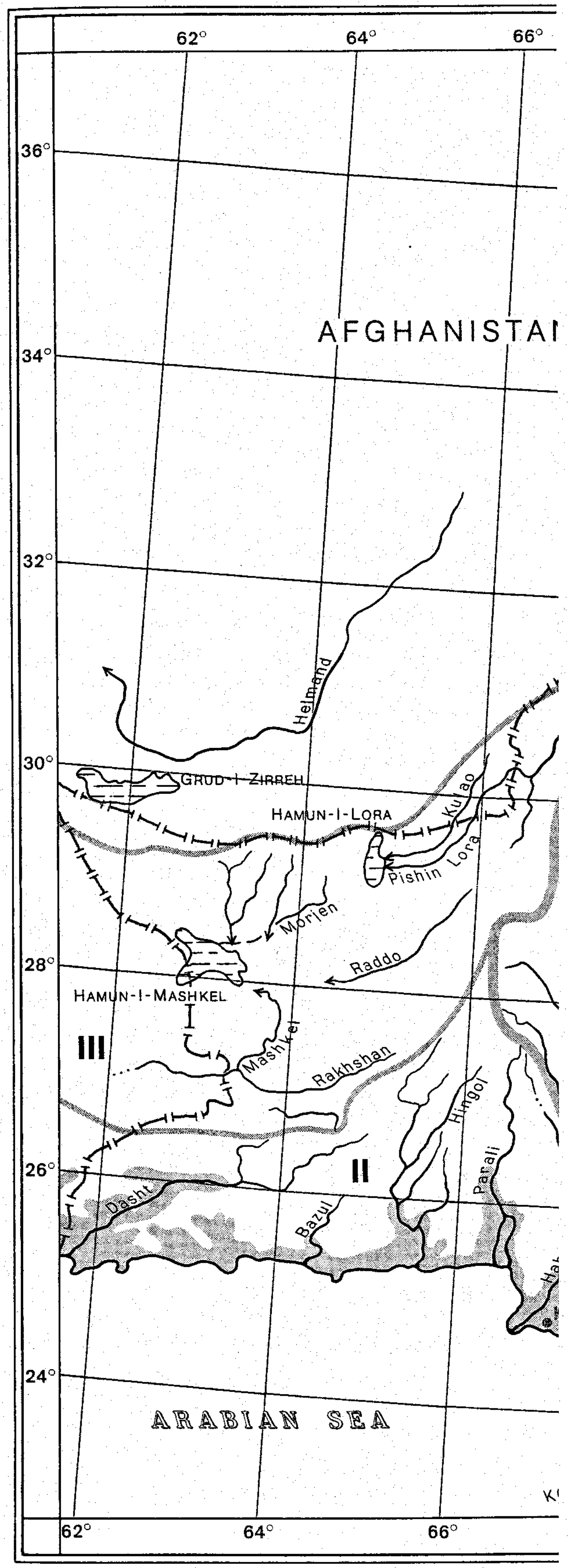


Fig. 10.1. Principle drainage pattern of Pakistan.

10. Water

(HANS BENDER)

Water is one of Pakistan's most precious and valuable resources especially because its uneven availability and the keen demand for it are on contrasting terms. Large parts of the country have an arid or semi-arid climate. About two thirds of the country receives less than 250 mm/a in precipitation. Rainfall is unevenly distributed not only in space but also in time. Most of it falls in the summer months (June, July, August), the period with the highest potential evapotranspiration. Rainfall in the mountainous region in the north, which amounts to a maximum of 2,000 mm/a, feeds streams heading south and causing floods through the arid lowlands towards the sea. Drinking water supply, agriculture, industrial development and generation of electrical power all depend on the availability of the resource "water".

The main water consumer of the country is agriculture, still the backbone of Pakistan's economy. Only a minor portion of the cultivated land is rainfed or sailab-irrigated. About three thirds of it must be irrigated ($25.5 \cdot 10^6$ acres), mostly by water from rivers and springs and to a minor extent from groundwater.

10.1 Surface water

Pakistan is divided into three general drainage basins (Fig. 10.1, fold-out):

- the Indus Basin,
- the Makran Coast Catchment,
- the Kharan Desert Catchment.

Most of the perennial rivers are fed by melt waters from the snow and ice cover of the high mountains. For agricultural purposes river water is stored or retained by reservoirs and headworks and led to its destination by the world's largest contiguous irrigation system.

10.11 Snow and ice as water resources

Large areas of the mountainous region are covered by snow in winter. This holds true mainly for the Himalayan part but happens also in the higher mountains of Baluchistan.

The perpetual snow line lies in the southern ranges of the Pakistan Himalayas at an altitude of 4,400 m ab.s.l. (v. WISSMANN 1959). Above this line perpetual snowfields and glaciers are developed.

A perceptible snowmelt starts within the Indus Basin in the beginning of April, continues over the summer period and ends in October. Seventy percent of the annual flow of the Indus and its tributaries is contributed by snowmelt (TARAR 1982). Fig. 10.2 shows exemplarily the relation between discharge of the Indus River at Besham and snowmelt in its catchment area.

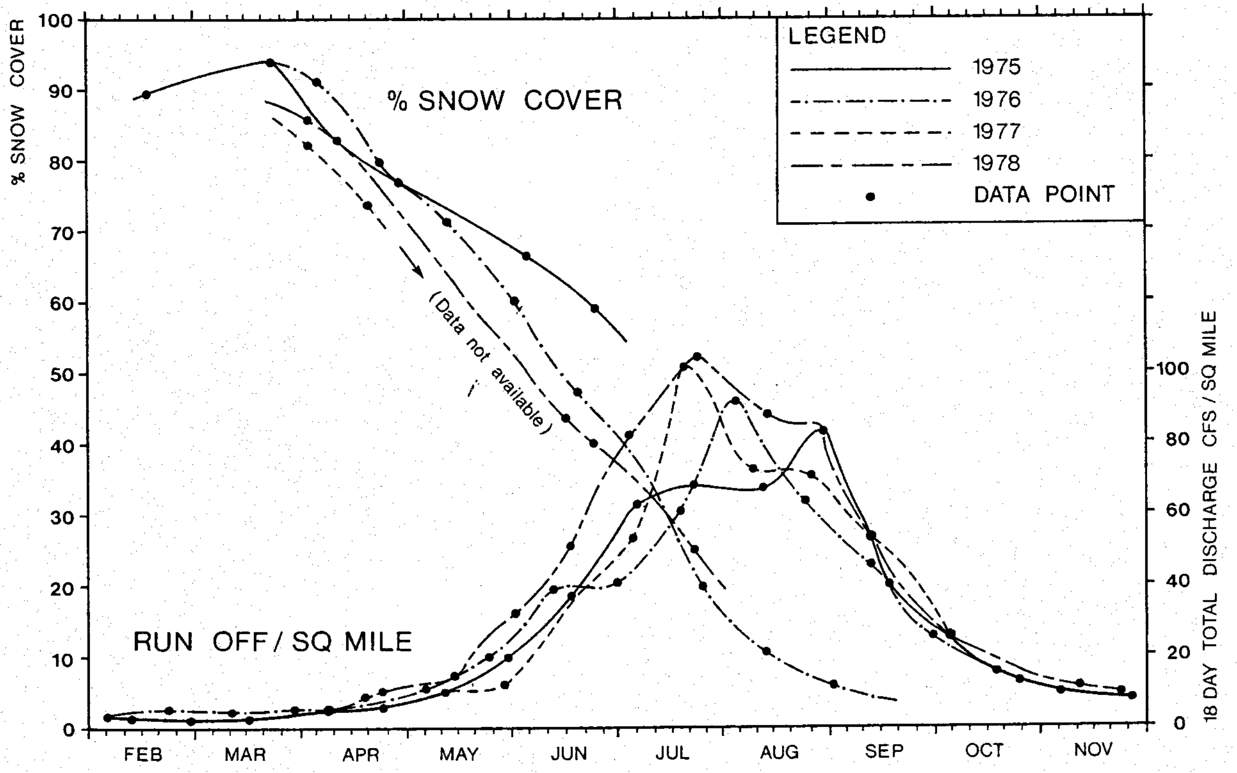


Fig. 10.2. Winter snow cover versus summer runoff (simplified after TARAR 1982). CFS = cubic feet per second.

10.2 The hydrogeological basins

10.21 The Indus Basin

The lowland of the Indus River system represents the northwestern part of the foredeep of the alpidic foldsystems, the Baluchistan Mountains and the Himalayas. The foredeep forms the subsiding margin of the Gondwanian-Indian Shield.

The Indus River forms the main drainage line of the northwestern part of the Indian subcontinent. Its entire length amounts to 3,180 km. When entering the plains of the lowland at Kalabagh the Indus has already covered a distance of more than half its total course flowing through mountain ranges which are part of the "roof of the world". Its source is situated near Mount Kailas (6,775 m). It is of interest that the Sutlej (the southernmost eastern tributary of the Indus) and the Tsangga (Brahmaputra) spring forth in the same area. Eastern tributaries of the Indus are Jhelum, Chenab, Ravi and Sutlej. The rivers Kabul, Kurram, Gumal and Gaj join from the west.

The coverage of the entire Indus River basin is in the order of one million km².

The limits of the catchment area of the Indus Basin are drawn in Fig. 10.1 as watersheds. Naturally not all the water which flows from the limits of the basin reaches the Indus River mainly due to the lack of a sufficient gradient, high infiltration capacity of the soils, high infiltration rates, and just due to the scarcity of rainfall. Of the numerous rivers which reach the Indus Plains coming from the Baluchistan Mountains only the Gumal and the Gaj Rivers flow through to the main river.

In general the water divide delineates the Indus system from the following hydrological units (in clockwise succession): the Makran coast basin, the Pakistan and Afghanistan part of the zone of closed basins, the Amudarja Basin, the Tarim Darya closed basin, the closed basins of the Tibetan highland, the Brahmaputra and the Ganges river systems.

The combined catchment area of the Indus and its tributaries, i. e. the actual area from which they receive their water, amounts to 551,700 km² (SCHOLZ 1985). The catchment area of the Indus River proper is 282,900 km². Flow quantities and particular catchment areas of the rivers of the Indus system are listed in Table 10.1 (after SCHOLZ 1985).

Table 10.1. Discharge of the Indus and its tributaries.

River	Gauging station (= G.S.)	Catchment area above the G.S. in 1,000 km²	Flows in 10^9 m³/a		
			av.	max.	min.
Indus	Kalabagh	282.9	114	148	75
Eastern tributaries:					
Jhelum	Mangla	33.0	28	41	16
Chenab	Marala	28.4	32	43	22
Ravi	Madhopur	7.9	8		
Beas	Mandi Plain	16.6	16		
Sutlej	Rupor	47.4	21	no data	
Western tributaries:					
Kabul	Nowshera	87.6	29		
Kurram	Thall	5.4	0.9		
Gomal	Kot Murtaza	35.6	0.4		
Gaj	Jubble	6.9	0.1		
Total		551.7	249.4		

The flow in the rivers varies seasonally, depending on run-off from summer monsoon-rain and snow and ice melt from the Himalayas. Accordingly, the flow is moderate in spring, high flood in summer, and low in winter (Fig. 10.3). The seasonal variations of river flow are extreme: 60 % of their total discharge occurs during a

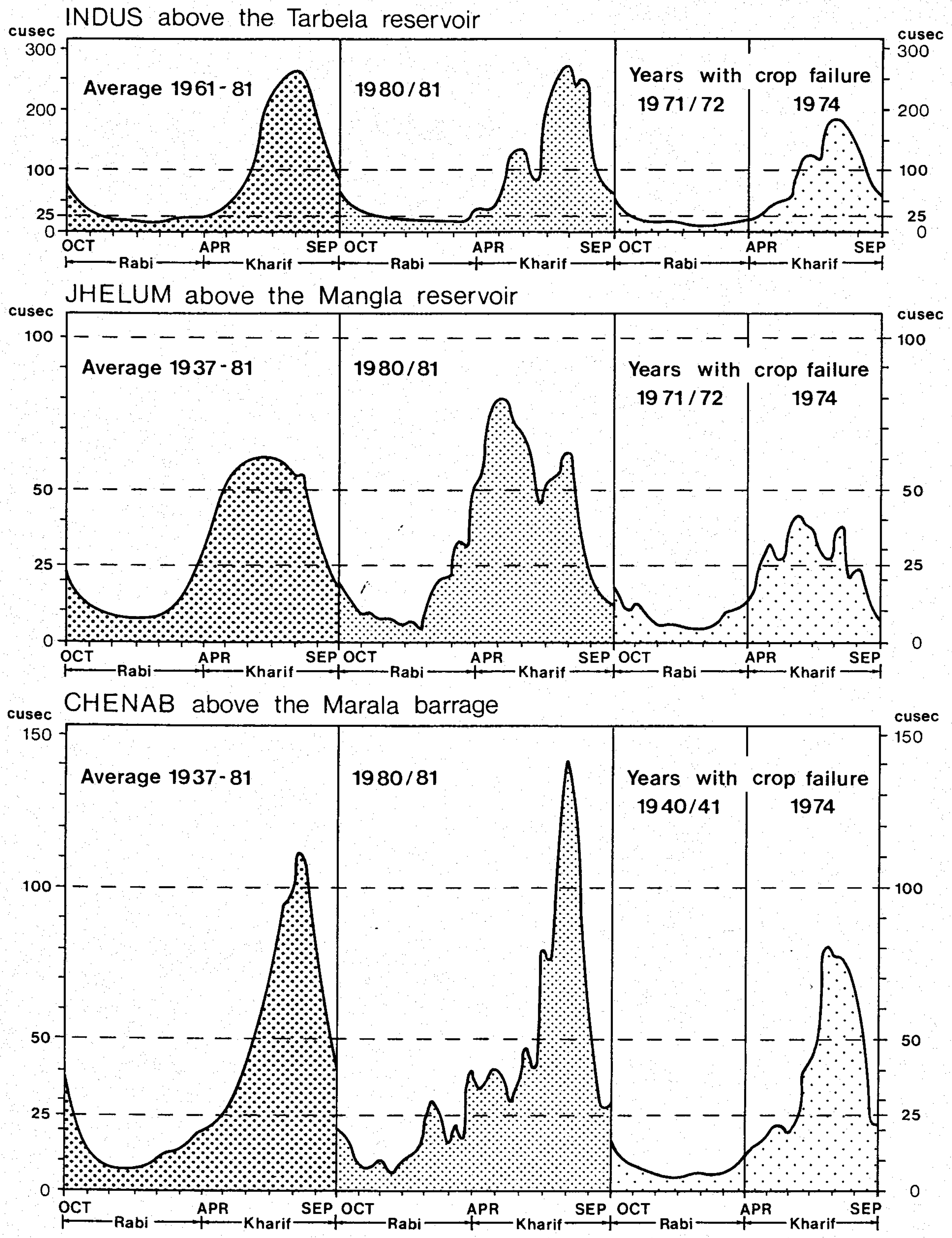


Fig. 10.3. Flow characteristics of the Rivers Indus, Jhelum and Chenab (adopted from SCHOLZ 1985); Rabi = winter, Kharif = summer, the two growing seasons of agriculture in lower Pakistan.

3 months period (June–August). The lowest discharge rates are measured during the winter (middle of December to middle of March). The main rise of the rivers begins by the middle of March with the snow break in the Himalayas and reaches a maximum with the run-off of the monsoon rains during June – August.

The northern and the southern parts of the Indus catchment area show extreme contrasts. The northern part is an area of high, partly glacier-capped mountains with average annual temperatures around or little above zero, receiving an annual precipitation of one to two meters, the southern part is a rather uniform lowland that has continental to arid climate with average summer temperatures of about 30 °C and moderate winter temperatures of 15 to 20 °C. Thus the Indus lowland is geographically favorable for irrigated agriculture.

The total area irrigated by the Indus and its tributaries within the limits of Pakistan amounts to approximately 14 million ha, distributed as follows (in million ha, state 1981, after SCHOLZ 1985):

Peshawar Basin	0.3
Punjab	8.2
Lower Indus	5.5

The intricate and ingenious irrigation system is shown schematically in Fig. 10.4. The dams or reservoirs serve for the storage of water for irrigation and drinking water as flood retention and for the production of electric energy. Information on the 3 existing dams and the planned Kalabagh reservoir is listed in Table 10.3.

Table 10.2 (after SCHOLZ 1985) shows the areas irrigated by the particular rivers.

Table 10.2. Cultivated and irrigated areas in the Indus plains.

River	Cultivated area in ha	%	Irrigated area 1980 in ha all year	%	partial	%	total	%
Indus	7,728,952	48.9	3,792,265	45.0	3,094,587	55.9	6,886,843	49.2
Jhelum	902,032	5.7	672,578	8.0	154,587	2.8	827,166	5.9
Chenab	2,869,180	18.1	1,703,702	20.2	791,148	14.2	2,494,851	17.8
Ravi	1,379,959	8.7	907,293	10.8	369,068	6.6	1,276,360	9.1
Chenab/Ravi	759,179	4.8	244,021	2.9	421,272	7.6	665,294	4.7
Sutlej	1,876,095	11.9	860,753	10.2	736,111	13.2	1,596,864	11.4
Kabul	22,220	0.1	19,425	0.2	–	–	19,425	0.1
Swat	275,182	1.7	234,715	2.8	–	–	234,715	1.7
Total	15,812,868	100.0	8,434,743	100.0	5,566,773	100.0	14,001,521	100.0

Source: unpublished record of the WAPDA, Lahore 1982.

Besides the reservoirs already in use, supplemental dams are planned or under construction at Kalabagh, Hub, Khanpur and Simla. The barrages or headworks are barriers built as solid dams across the river beds in order to divert water for irrigation which is then led by feeder canals to the respective command areas. The headworks are also used to control river flow.

The link canals transfer water from the Indus, Jhelum and Chenab Rivers to the eastern part of the Pakistan Punjab. They were built to compensate for the water shortage which occurred after the partition of the Indian Raj when the headwaters of Ravi, Beas and Sutlej were allocated to India.

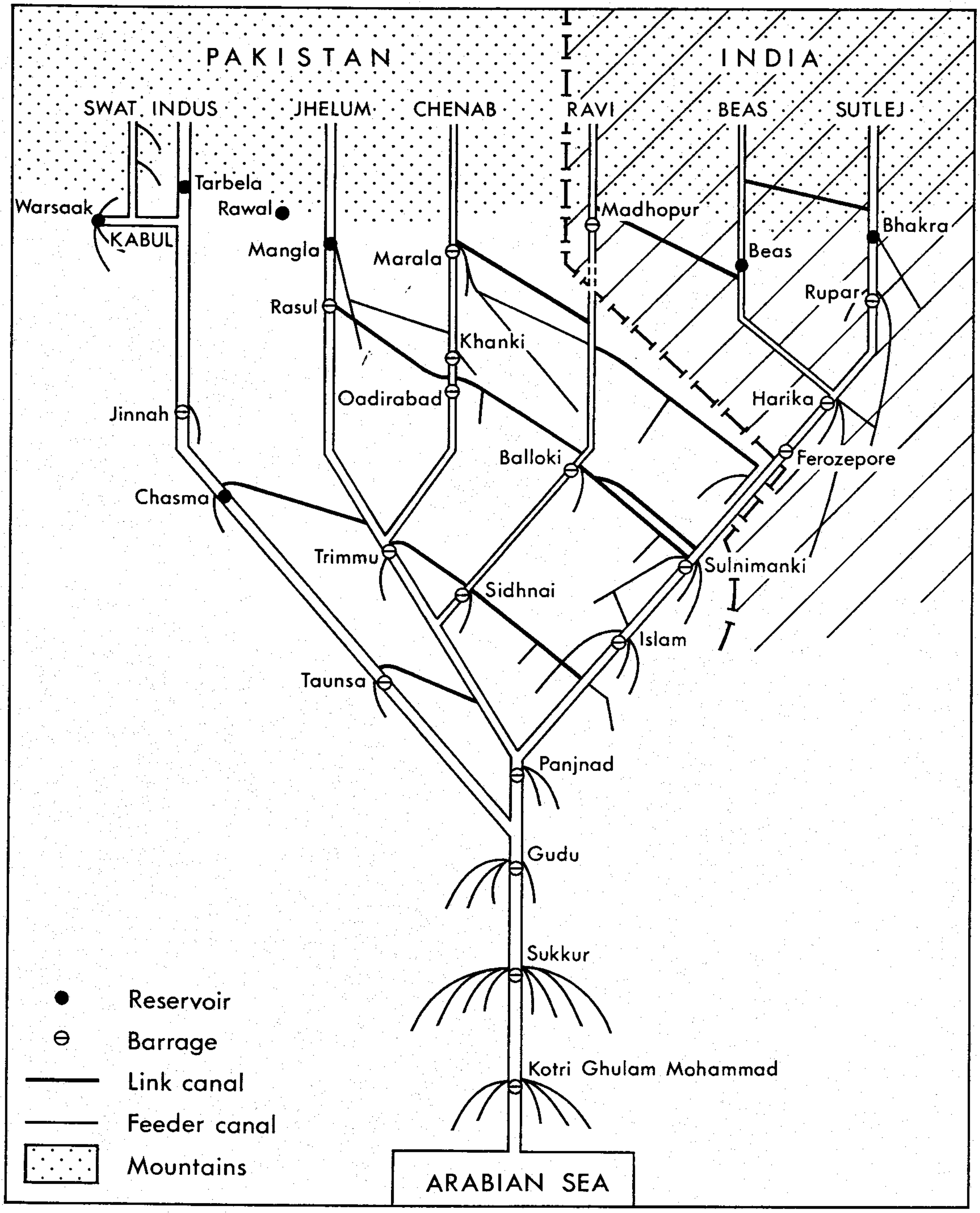


Fig. 10.4. The irrigation system of the Indus Plain (simplified after SCHOLZ 1985).

Table 10.3. Data on reservoirs in the Indus River catchments (after AHMAD & CHAUDRY 1988).

reservoir (on river)	year of construction	type of dam	dam's length [m]	dam's height [m]	storage capacity gross [$m^3 \cdot 10^6$]	storage capacity live [$m^3 \cdot 10^6$]	crest elevation a.s.l. [m]	rate of depletion *) [$m^3 \cdot 10^3$/year]	Catchment area [km^2]
Warsak (Kabul)	1960	concrete gravity	140	76	0.17	0.03	387	(high)	67,300
Mangla (Jhelum)	1960	earthfill	3,350	100	6.85	1.61	376	42	34,140
Tarbela (Indus)	1968 – 1975	earth and rockfill	2,740	148	13.69	11.47	477	192 (average)	
Kalabagh (Indus)	planned	earthfill	1,265	81	11.56	9.59	288		391,600

*) of the storage capacity by silting up

10.211 The Punjab

Information on this area derives mainly from GREENMAN, SWARZENSKI & BENNET (1967). The Punjab covers an area of about 102,400 km². Its elevation ranges from 110 m to 625 m a.s.l. The Punjab is bordered in the north by the Salt Range, in the northeast by the Himalayan foothills, in the southeast by the Sutlej River, and in the west by the Indus River.

The vast Punjab Plain provides only very low gradients, $0.13\,^{0}/_{00}$ at its lower southwestern end and $0.26\,^{0}/_{00}$ near the Himalayan foothills. Its water balance (inflow and drainage) is controlled by the prominent 5 rivers of the area (Punjab = Land of Five Rivers), the Indus and 4 of its tributaries. The intermediate areas between the rivers are called "doabs" or "bar" uplands (doab = two waters; bar = high). The following arrangement shows in clockwise sequence the rivers (their approx. lengthes) and doabs [with their areal extend]:

Indus River	(460 km, in the Punjab)
Thal Doab	[31,970 km²]
Jhelum River	(300 km)
Chaj Doab	[12,950 km²]
Chenab River	(470 km)
Rechna Doab	[28,330 km²]
Ravi River	(410 km)
Bari Doab	[29,140 km²]
Sutlej River	(480 km).

The doabs rise in their centres by about 15 m above the flood plains of the rivers. The flat relief of the plains is broken by some scattered isolated bedrock hills in Chaj Doab (Kirana Hills, 300 m above the plain) and Rechna Doab (Pappi Hills, part of the Himalayan foothills, 165 m above the plain), and by extensive dune areas in the central desert of Thal Doab.

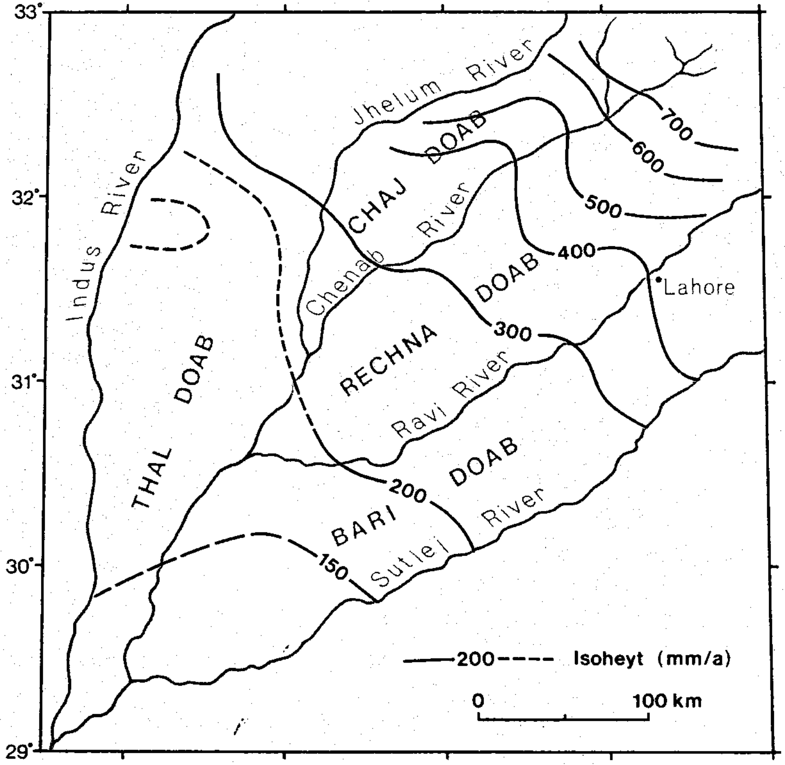


Fig. 10.5. Isohyetal map of the Punjab (adopted from GREENMAN et al. 1967).

GREENMAN et al. (1967) divided the Punjab into the following morphological units: Bedrock hills, piedmont areas, alluvial plains. The latter are subdivided into active flood plains, abandoned flood plains and bar uplands (Fig. 10.6). The bedrock hills do not play any remarkable role in the groundwater regime of the area. The piedmont areas act as a transitional zone between the alluvial plains and the mountainous areas of the Salt Range and the Himalayan foothills, and they merge gradually into the plains. The piedmont areas consist mainly of alluvial fans which are dissected by hill torrents and few perennial rivers.

In the piedmont areas the groundwater table receives a considerable amount of recharge due to the relatively high rainfall (up to 750 mm/a) and the natural spreading of the water torrents and perennial rivers over the talus fans, which consist of coarser detrital material compared with the alluvial sediments of the plain. The groundwater formed in the piedmont areas thus contributes to a considerable extent to the entire groundwater throughput of the plains.

The alluvial plain is underlain by a sequence of detrital sediments at least 350 m thick except near the bedrock outcrops. The total thickness of the unconsolidated alluvium is not generally known; few exploratory boreholes drilled to a depth of about 500 m still bottomed in alluvial sediments. The material derived from the mountainous areas in the north and northeast was deposited by the Indus River and its present and former tributaries. Due to reworking and redeposition of sediments caused by shifting of the rivers, the sedimentary sequence is not homogeneous. The sediments range from gravel to clay, but gravel, silt and clay are rare and sand predominates.

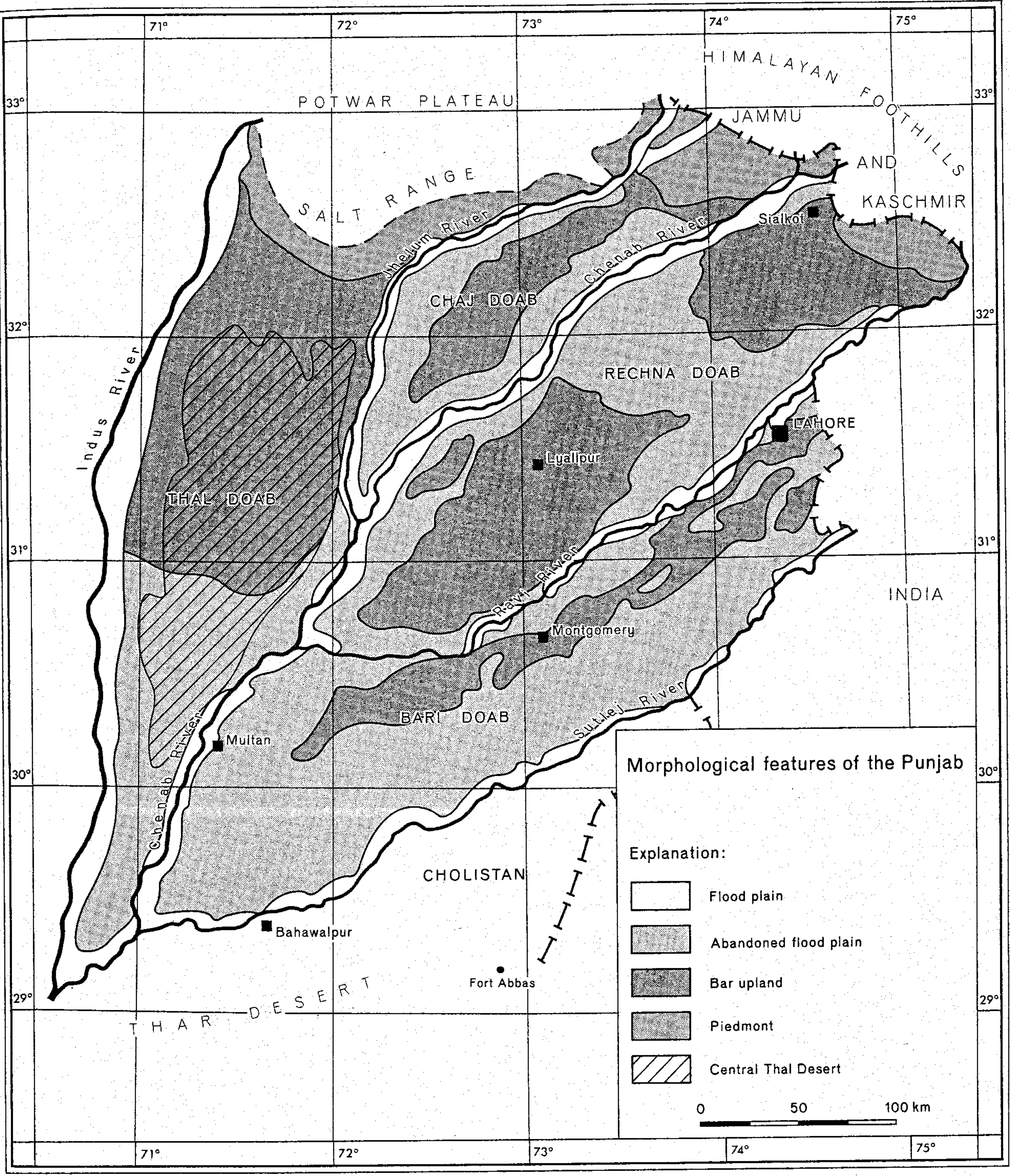


Fig. 10.6. Morphological features of the Punjab (simplified after GREENMAN et al. 1967, Plate 2).

The active flood plains include the meander belts and the present flood plains of the principal Punjab rivers. These active flood plains, together with the perennial river channels, provide the main source for the recent recharge to the aquifer system of the Punjab. The active flood plains are as much as 2.5 km in width. The abandoned flood plains, bordering the active ones, form a transition zone between these and the bar uplands. They are only slightly higher than the active flood plains and, in places, are subject to occasional flooding. The subsurface distribution of fresh and salt water in some areas, where the freshwater zones are exceptionally wide and extend far from the existing rivers, apparently reflects the former recharge capacity of the abandoned flood plains, as illustrated by the Beas River (Chapter 10.212).

The bar uplands (doabs) occupy the intermediate spaces between the active and abandoned flood plains. They rise as much as 15 m above the flood plains and are no longer subject to river floods, but still carry traces of fluvial activity and represent the remnants of an older Indus system's plain. The groundwater under the bar uplands receives surface water only in the form of rain.

The alluvial complex of the Punjab represents the latest phase of sedimentation in a subsiding trough, the foredeep of the rising Himalayas. It consists of a sequence of inter-fingering layers of varied permeabilities (mainly of medium to fine grained sand with some intercalations of clay). Due to the relatively unsorted sedimentation in a fluvial environment, the individual layers have but little continuity. An inhomogeneous aquifer system formed in such a way can be expected to have, in general, a rather uniform regionally-effective permeability because local occurrences of layers with extremely low or high permeabilities have no far-reaching influence. However, a comparison of cross sections given by GREENMAN et al. (1967) shows regional differences in the distribution of fine-grained material: There is a relatively higher accumulation of silt and clay in all upper parts of the Doabs and generally in the Chaj Doab. The Thal Doab shows relatively the highest sand content (Fig. 10.7).

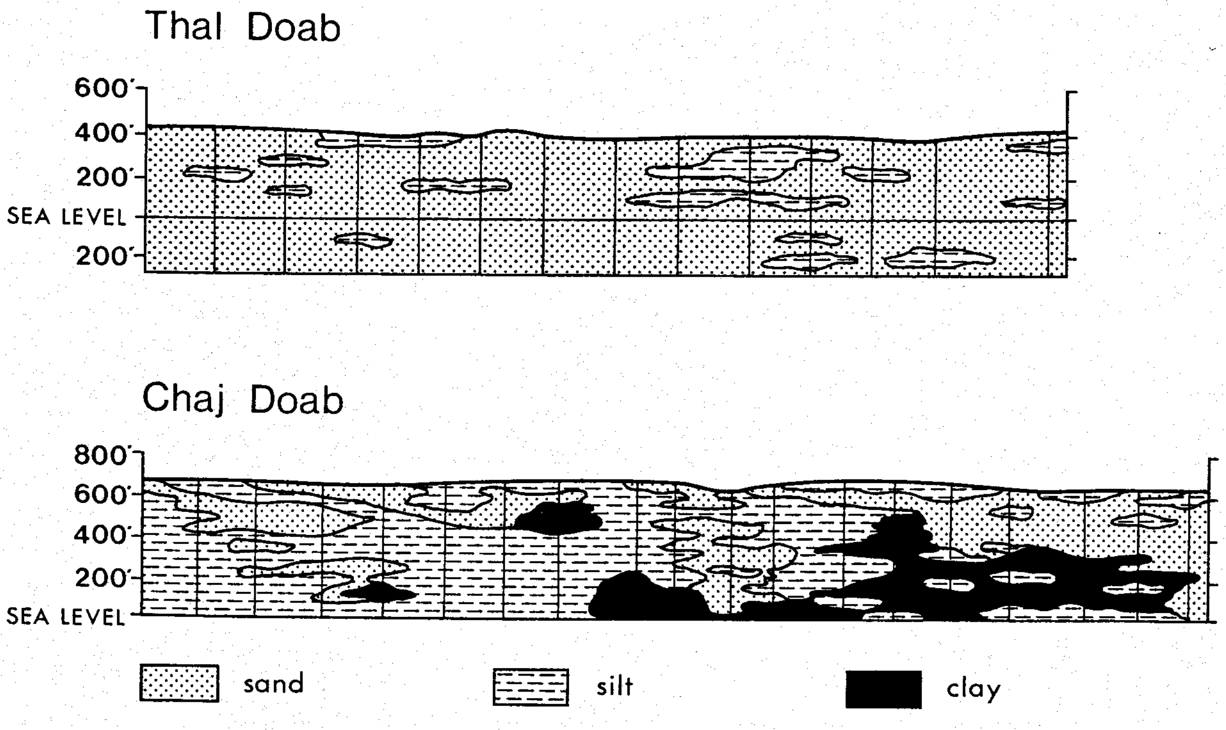


Fig. 10.7. Sections across the Thal and Chaj Doabs (simplified after GREENMAN et al. 1967). The cross sections run from NW (left) to SE (right).

In the flood plain areas the alluvium is filled with groundwater nearly up to the ground surface. Near the rivers the depth to groundwater is almost zero. Below the bar uplands the depth amounts to only a few meters, whereas prior to the start of irrigation it was 20 m to 35 m (Fig. 10.8).

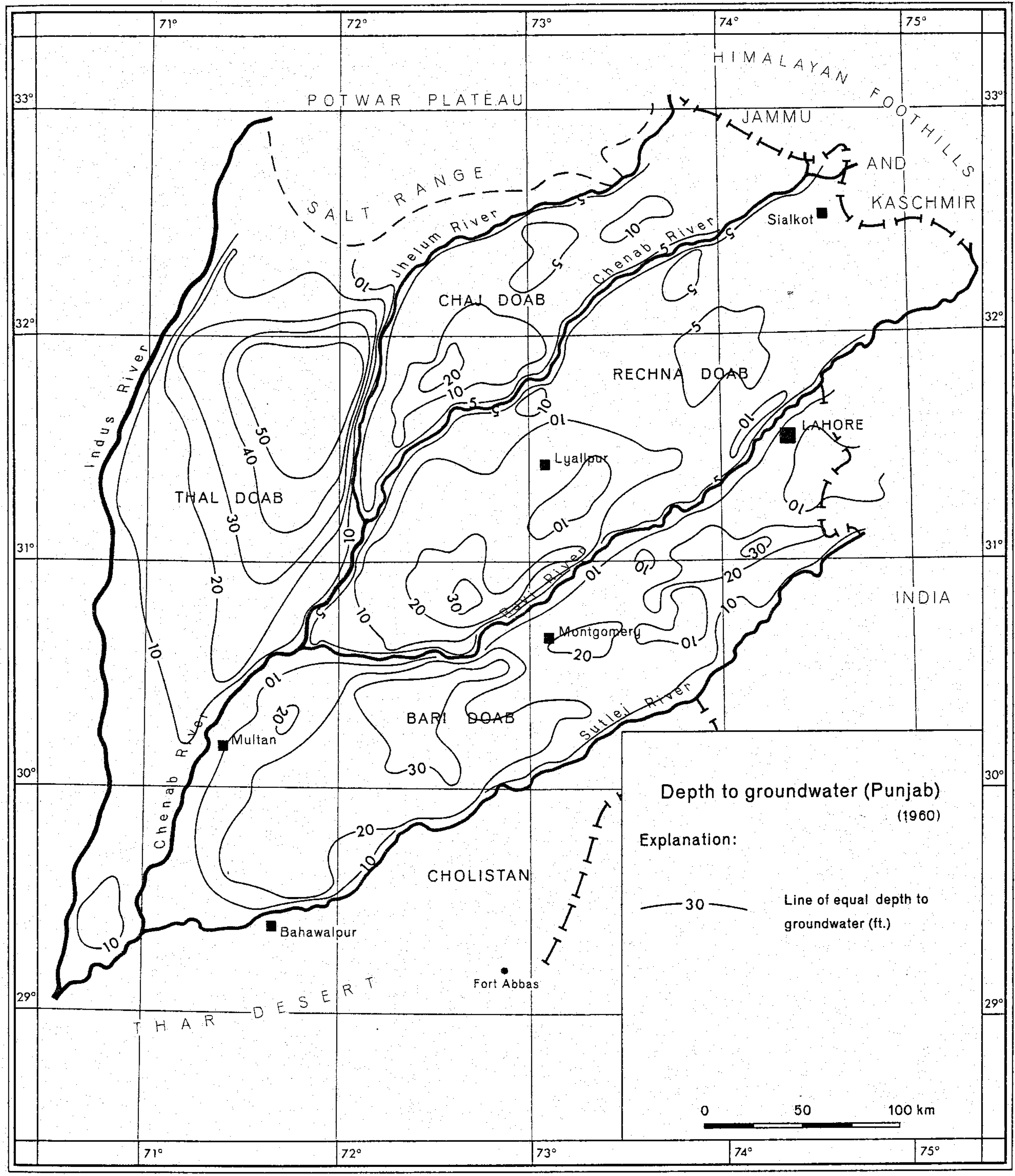


Fig. 10.8. Depth to groundwater in the Punjab (after GREENMAN et al. 1967).

The sedimentary sequence of the alluvial plain shows a more or less constant difference between horizontal and vertical permeability, the latter being the lesser one.

The average horizontal permeability found in 141 pumping tests (BENNET et al. 1967) amounts to $9.75 \cdot 10^{-4}$ m/s. About 71 fall in the range of $3.66 \cdot 10^{-4}$ to $1.19 \cdot 10^{-3}$ m/s (Fig. 10.9). The results gained in the different doabs are listed in Table 10.4.

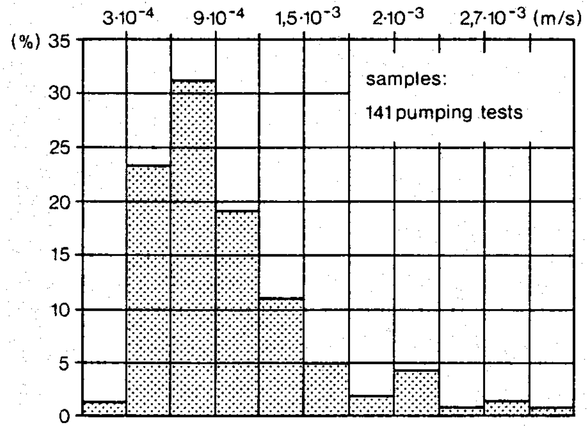


Fig. 10.9. Distribution of horizontal permeabilities of screened intervals in the Punjab (modified after BENNET et al. 1967).

Table 10.4. Horizontal permeabilities (k) from pumping tests.

doab	No. of tests	average k (m/s)	percent	fall in the range of (m/s)
Thal	35	$1.1 \cdot 10^{-3}$	68	$5.1 \cdot 10^{-4} - 3.7 \cdot 10^{-3}$
Chaj	36	$0.53 \cdot 10^{-4}$	69	$5.49 \cdot 10^{-4} - 1.04 \cdot 10^{-3}$
Rechna	49	$1.16 \cdot 10^{-3}$	69	$7.62 \cdot 10^{-4} - 1.04 \cdot 10^{-3}$
Bari	21	$7.92 \cdot 10^{-4}$	67	$3.05 \cdot 10^{-4} - 6.1 \cdot 10^{-4}$

The vertical permeability values as determined by pumping tests fall in the range of $3 \cdot 10^{-4}$ to $3 \cdot 10^{-6}$ m/s. For the tests performed the ratio of the horizontal permeability of the screened intervals to the vertical permeability of the overlying section ranges between 3.3 : 1 and 195 : 1; the average of this ratio of anisotropy for the 14 tests is 76 : 1. Porosity values were determined by laboratory tests on repacked drill cuttings. From these studies the average porosity of the alluvial sands is estimated to be 0.35.

GREENMAN et al. (1967) reconstructed a water table contour map of the Punjab based on available records from the pre-irrigation period (Fig. 10.10). In the upper part of the Bari Doab, however, the original conditions had been already altered at the time of this study by seepages from the upper Bari Doab canal system which was opened in 1858.

With the exception of the uppermost parts of all doabs southeast of the Chenab River a conspicuous trough in the groundwater table, showing a pronounced upgradient curvature of equipotential lines, has developed beneath the doabs. The axes of the troughs follow the middle line of the doabs. The flow lines resulting from the groundwater contour plan are directed to the southwest (basinwards) in the upper part of the doabs, lead away from the rivers in the lower part of the doabs and converge below them. The interpretation of this flow net in respect to recharge, groundwater movement and discharge is the following: Most of the recharge is caused by infiltration of water from the rivers which are of influent nature. Sub-terranean inflow to the Punjab

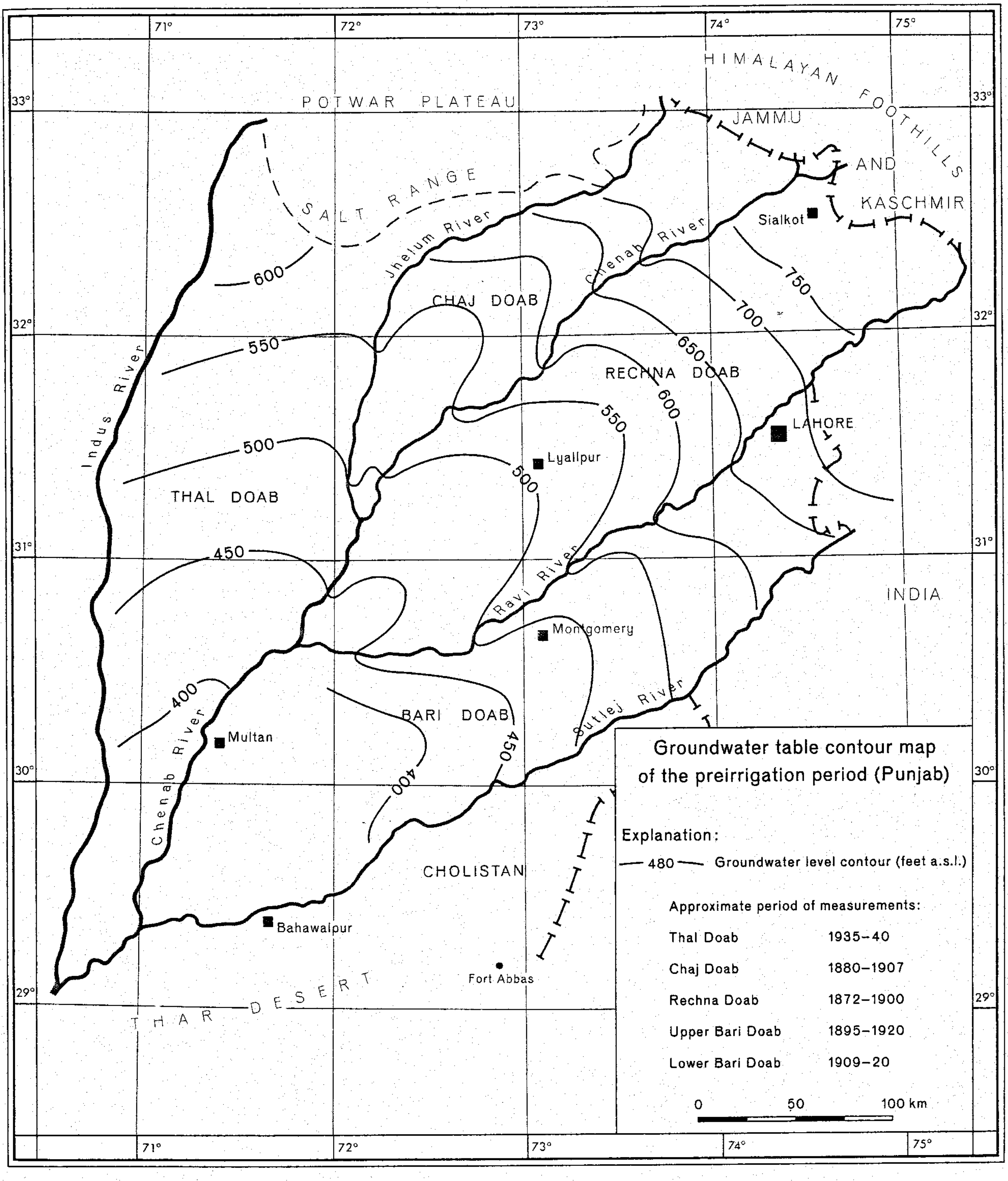


Fig. 10.10. Groundwater table contour map of the pre-irrigation period in the Punjab (simplified after GREENMAN et al. 1967, Plate 8).

Basin occurs at the upper end of the doabs and there, most probably, also groundwater replenishment takes place by direct infiltration from the relatively high rainfall of the area (Fig. 10.5). This is indicated by the steepening of the hydraulic gradients at the upper end of the doabs.

There is almost no discharge of groundwater back to the rivers, except in the lower part of the Chenab which acts as a drainage line for the groundwater flow. Most of the groundwater discharge is by evapotranspiration directly from groundwater. This takes place in the lower parts of the doabs and in the areas between the rivers near their confluents. This is expressed in the groundwater table by the flattening of the hydraulic gradients.

A different flow system is observed under the Thal Doab: The inflow from the Chenab to the west is obviously small and the role of this river is reversed in its lower course, where groundwater flows to the Chenab. The inflow from the Indus is predominant and in the lower part of the doab the groundwater passes diagonally across the doab and discharges into the Chenab.

Fig. 10.11 shows the hydraulic fundamentals of the system. It is determined by two zones of adverse groundwater movement: Downward movement occurs below the influent rivers and upward movement in the center of the doab where groundwater is lost to evapotranspiration.

The quantification of groundwater throughput under pre-irrigational conditions (flow net analysis) has been determined using the average permeability values of each doab as listed above and a general thickness of 350 m of the alluvium. This was tried in order to assess the groundwater quantities in their order of magnitude which took part

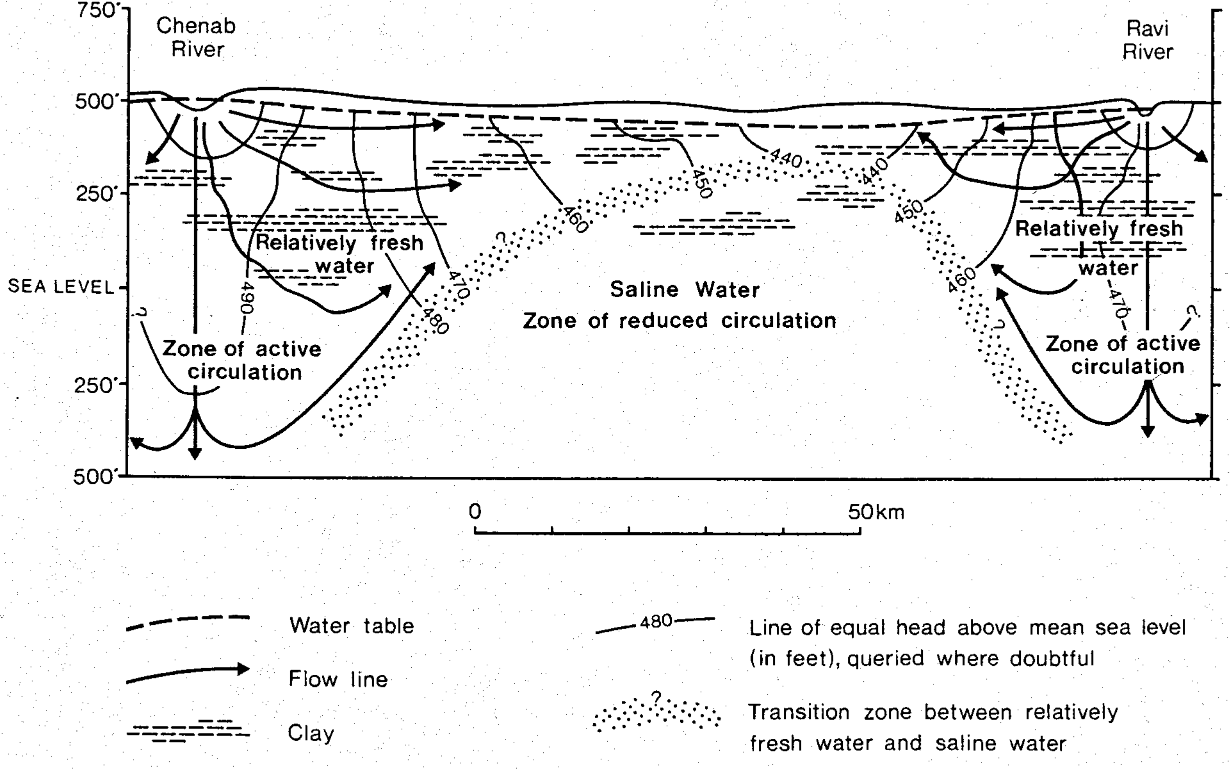

750'
500'
250'
SEA LEVEL
250'
500'
Chenab River
Ravi River
Relatively fresh water
Saline Water
Zone of reduced circulation
Zone of active circulation
Relatively fresh water
Zone of active circulation
440
450
460
470
480
490
?
0
50km
Water table
Flow line
Clay
480
Line of equal head above mean sea level (in feet), queried where doubtful
Transition zone between relatively fresh water and saline water

Fig. 10.11. Hydraulic profile for Rechna Doab, pre-irrigation period (after GREENMAN et al. 1967).

Table 10.5. Pre-irrigation groundwater balance of the Punjab.

Doab		Q (10^9 m^3/a)	
Thal:	Underflow from Indus R.:	0.93	
	Underflow from Jhelum R.:	0.05	
	Underflow from Chenab R.:	0.03	
	Inflow*:	none	
	Discharge to Chenab R.:	0.32	
	Evapotranspiration losses:	0.69	
Chaj:	Underflow from Jhelum R.:	0.81	
	Underflow from Chenab R.:	0.61	
	Inflow*:	none	
	Evapotranspiration losses:	1.42	
Rechna:	Underflow from Chenab R.:	1.15	
	Underflow from Ravi R.:	1.21	
	Inflow*:	0.40	
	Discharge to Ravi R.:	0.05	
	Evapotranspiration losses:	2.71	
Bari:	(gw contours from 1890 – 1910)		
	Underflow from Ravi R.:	0.97	
	Underflow from Sutlej R.:	0.61	
	Inflow*:	0.29	
	Discharge to Ravi R.:	0.06	
	Discharge to Sutlej R.:	0.12	
	Evapotranspiration losses:	1.70	
overall balance:			
	Underflow from rivers:		6.37
	Inflow*:		0.70
	Discharge to rivers:		0.54
	Evapotranspiration losses:		6.52

* Inflow is that part of the groundwater flow which enters the plain in the section between two rivers and is generated in the piedmont area not being influenced by indirect recharge from the rivers but created by direct recharge from precipitation.

in the groundwater balance in the pre-irrigation period. The results of this analysis are listed in Table 10.5.

Fig. 10.12 shows the regional distribution of the salt content of the groundwater. GREENMAN et al. (1967) believed that groundwater below a depth of 30 m was still unpolluted by higher saline shallow groundwater during the time of their study, the actual high salinities of the shallow groundwater being caused by irrigation activities. It is further thought that the areal distribution of salinities found by this method represent the original conditions of the pre-irrigation period.

The distribution of fresh and saline groundwater reflects the principles of the hydraulic system: Zones of fresh groundwater border the rivers and coincide with the areas of the downward moving underflow from the rivers and their adjacent flood plains. Areas of saline to highly saline groundwater are situated in the centers of the

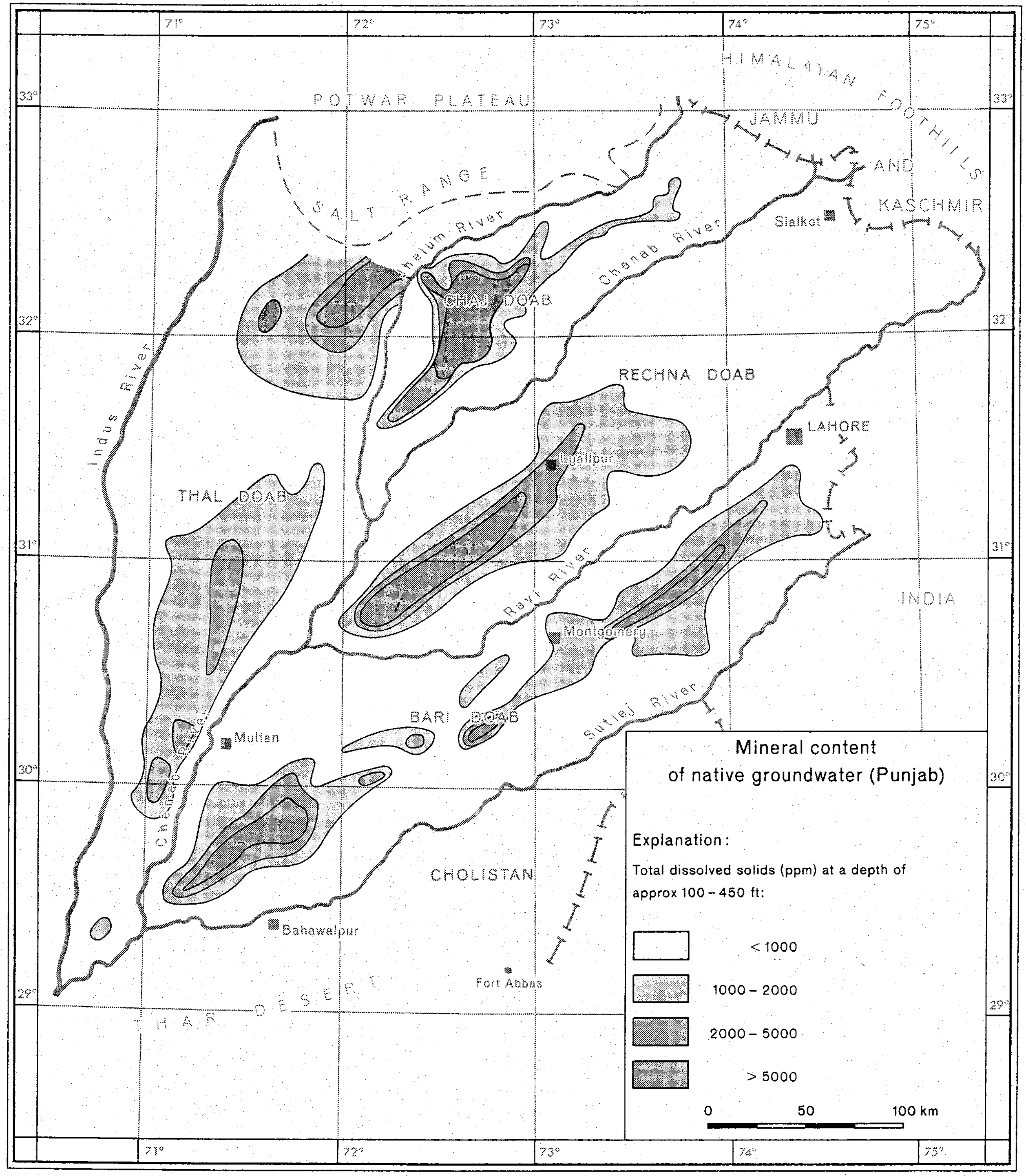


Fig. 10.12. Mineral content of "native" groundwater in the Punjab (simplified after GREENMAN et al. 1967, Plate 9).

doabs as well as in the triangles of the confluents of the rivers, where upward-moving groundwater is lost to evapotranspiration. The highest salinities which occur in the different doabs are listed in Table 10.6.

Table 10.6. Maximum groundwater salinities (figures approximate).

Doab	
Thal	
northern part	10,000 ppm
southern part	4,000 ppm
Chaj	20,000 ppm
Rechna	10,000 ppm
Ravi	5,000 ppm

An increase in the total salinity and also a change in the ionic composition of dissolved material occur with distance from the rivers. These changes are summarized in Table 10.7.

Table 10.7. Salinity and hydrochemical characteristics.

Salinity	composition
200 – 500 ppm	calcium magnesium-bicarbonate water
300 – 1,000 ppm	sodium bicarbonate water predominant
500 – 1,000 ppm	sodium bicarbonate water
2,000 – 3,000 ppm	increase of sulfate and chloride content with little or no increase in bicarbonate
4,000 ppm and more	generally sodium chloride water

Both the rise of the water table and changes of groundwater quality have resulted from the methods of irrigation. The oldest method of irrigation in the Punjab is the flood irrigation ("sailab"). Canal irrigation began in the Punjab at the end of the 17th century with the construction of inundation canals which drew water from the rivers during their high flood stages and could serve the irrigation of upland areas bordering the active flood plains. By the middle of the 19th century a rather extensive network of inundation canals was in operation concentrated along the Sutlej and Chenab Rivers.

Modern diversion works made it possible to lead river water far away from its source, into the centers of the higher elevated doabs during a great part of the year, or even perennially. The first canal system relying on a diversion structure was the upper Bari Doab Canal (1859). Further canal construction includes: Lower Chenab Canal in Rechna Doab (1896), lower Jhelum Canal (1901), upper Chenab, upper Jhelum, and lower Ravi Canals (1915). Between 1915 and 1930 the inundation canals fed by the Sutley River were converted to perennial canals. In 1958 all canals serving irrigated areas in the Punjab had been converted to their control. The irrigation canal system as it existed in 1967 is shown in Fig. 10.13. A more recent state of the irrigation system (1981) is represented in Chapter 10.21.

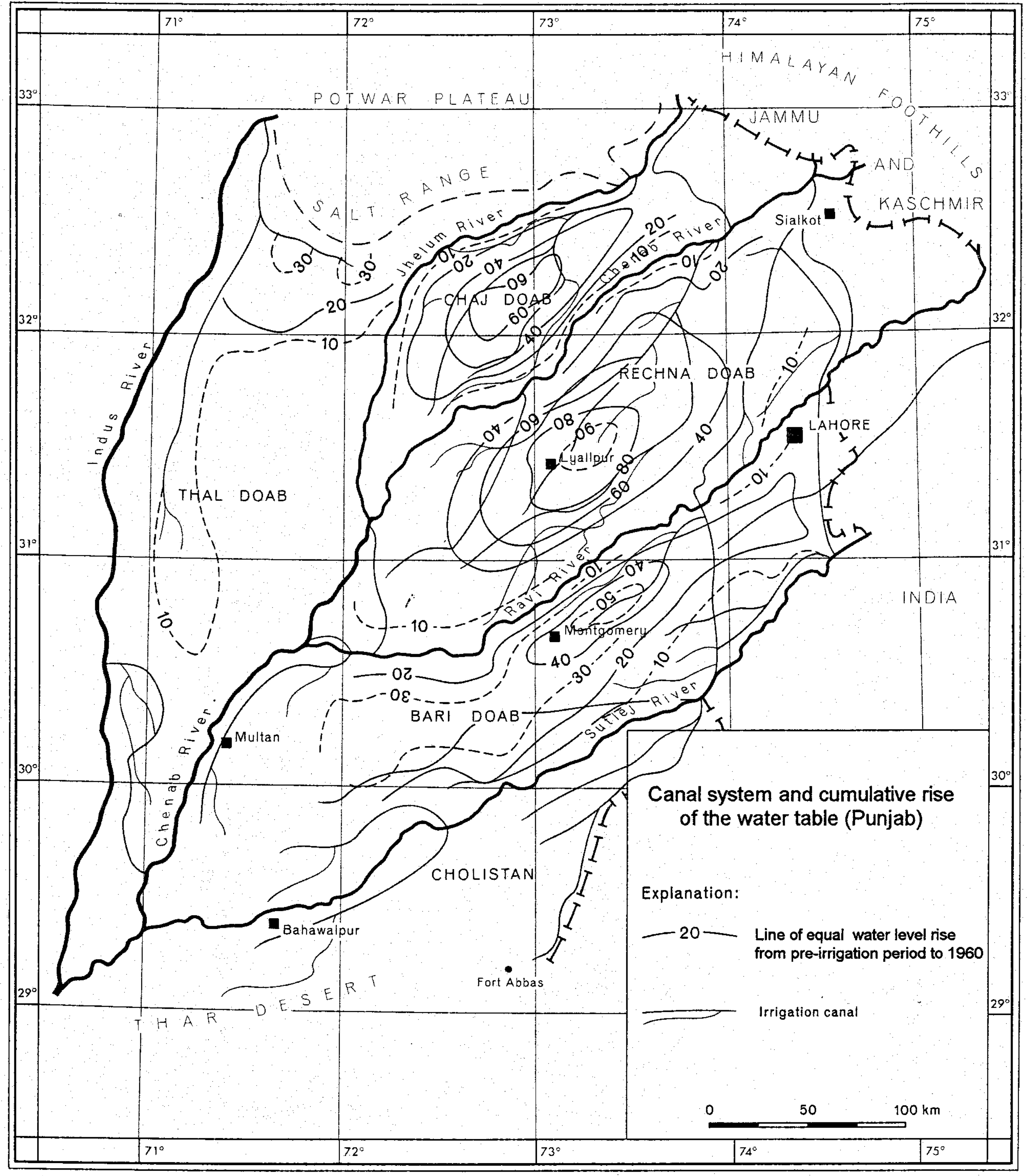


Fig. 10.13. Canal system and cumulative rise of the water table in the Punjab (simplified after GREENMAN et al. 1967, Plate 1).

The areas of agricultural land as they were served with irrigation water from the rivers and the respective water quantities are listed in Table 10.8.

Table 10.8. Irrigated areas and irrigation water served.

	Irrigateable area served (million ha)	Billion (10^9) m^3/a average: 1950-1959
Thal, Chaj, Rechna and Bari Doabs	6.03	41.8
Dera Ghazi Khan	0.20	2.0
Cholistan	1.30	10.7
Total	7.53	54.5

According to GREENMAN et al. (1967) up to 50 % of the canal water was lost by seepage into the underground. This added increment of groundwater could not be removed by the hydraulic system because of the low gradients. As a consequence the water table rose up nearly to the land surface. These conditions caused a new equilibrium in which discharge from groundwater by evapotranspiration was drastically increased. GREENMAN et al. (1967) show that the rise of the water table started around the year 1900. In the years 1930 to 1940 the water table reached the land surface. Fig. 10.14 shows the generalised development of the groundwater level in time, Fig. 10.13 the cummulative rise of the water table in the entire area.

It is expected that only the shallow groundwater, i. e. the interval between the native groundwater and the existing water table (between about 1 m in the flood plains and more than 30 m in the center of the doabs) is affected by the general rise of the water table. However, the quality distribution of near-surface groundwater still reflects in general the quality distribution of the native groundwater. Local changes have occurred in the immediate vicinity of irrigation canals in zones of originally saline groundwater which by dilution has now an improved quality.

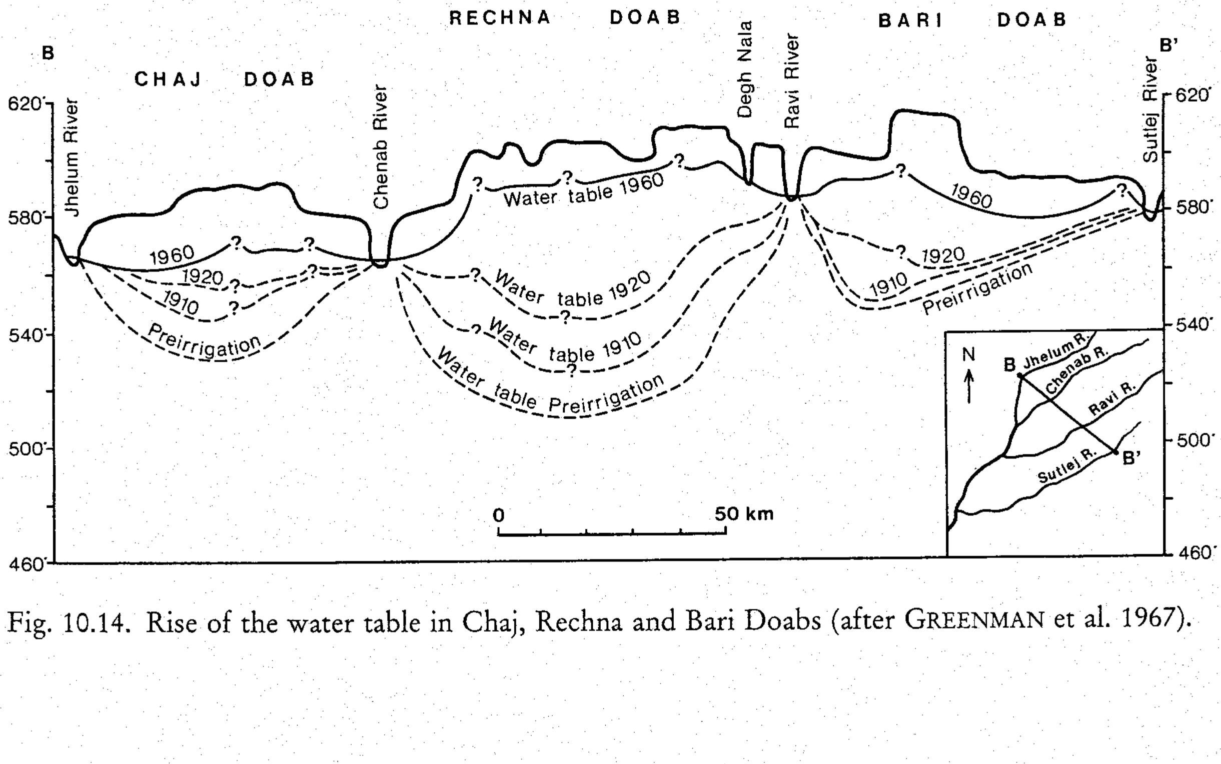


Fig. 10.14. Rise of the water table in Chaj, Rechna and Bari Doabs (after GREENMAN et al. 1967).

The drastic effects of the rising water table on agriculture are caused by the increased evapotranspiration due to its rise near the land surface. In addition to the generally poor drainage conditions in the extremely flat plain of the Punjab this led to progressive salinization and water logging, both being severe obstacles to agriculture. RATHUR (1987) published data on the actual situation concerning the extent of water logging and soil salinity in the Punjab (Table 10.9).

Table 10.9. Area affected by water logging and soil salinity in the Punjab.

Water logging (million ha):

	area affected		
gross command area	severely (water table at 0 – 1.5 m)	moderately (water table at 1.5 – 3 m)	total
9.63	0.58	2.43	3.01

Soil salinity (million ha):

area surveyed	normal soils	slightly saline (less than 0.2 % soluble salts)	moderately saline (0.2 – 0.5 % soluble salts)	highly saline (more than 0.5 % soluble salts)
9.50	7.07	1.41	0.40	0.62

10.212 Cholistan (Bahawaepur)

Cholistan is an area of complex depositional features that extends west from the Indian border to the Indus Plain, and south from the Sutlej River to the Thar Desert (Fig. 10.1). It covers an area of about 26,400 km^2 and is between 110 m and 260 m above sea level. The morphological features of Cholistan are characterized by aeolian, fluviatile and playa deposits. The aeolian sand deposits are parallel-ridged dunes (about half a mile long, striking SW – NE, max. height approx. 25 m, mostly consolidated), and transverse dunes running at right angles to them. Both consist of fine to very fine silty sand. The fluviatile deposits consist of mostly fine silty sand, with rare layers of medium-grained sand. These sediments occur in a fringe about 50 km wide south of the Sutlej River ending at about a line between Fort Abbas and Derawar Fort. The Playa deposits (mud flats) are of varying extent (several hundred metres to several kilometres across).

Cholistan can be considered as an ancient part of the Punjab River Plain, and in the Vedas[1] is referred to as the "Land of the **Seven Rivers**". Quite a number of scholars, historians and geographers have been occupied by the problem of identifying the two "lost rivers".

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[1] The Vedas (veda = knowledge in ancient sanskrit) are the first handed down scripts of the Indoaryan peoples who invaded the subcontinent from the north. The Vedas' date of origin is estimated to be in the period 1,200 to 600 B.C.

WILHELMY (1969) gave a plausible description of the development of the river systems of the Indus Plain during historical times: The drastic changes in the drainage system of the plain which happened during the last 4,000 years are most probably not due to climatic changes but happened in the watershed area between the Indus and Ganges River systems. At about 1,500 to 1,000 BC the Jumna River, which up to that time had belonged to the Indus system, changed its course and joined the Ganges system instead. This could be accomplished by minor changes in the elevation caused by tectonic movements in the very flat watershed area dividing the two giant river systems. In particular, the history of the Indus River system can be described as follows: Around 2,000 BC the original Jumna was still flowing from the foothills in southwestern direction passing the Cholistan settlements Derawar, Dinghar, Marot. It had the original (Veda-) Sutlej as its tributary (Fig. 10.15). Most probably the original Jumna did not join the Indus River at all but flowed parallel to it through the western part of the Thar Desert (known as Hakra-Nara in ancient documents) and had its own mouth at the Kori Creek in the Rann of Kutch.

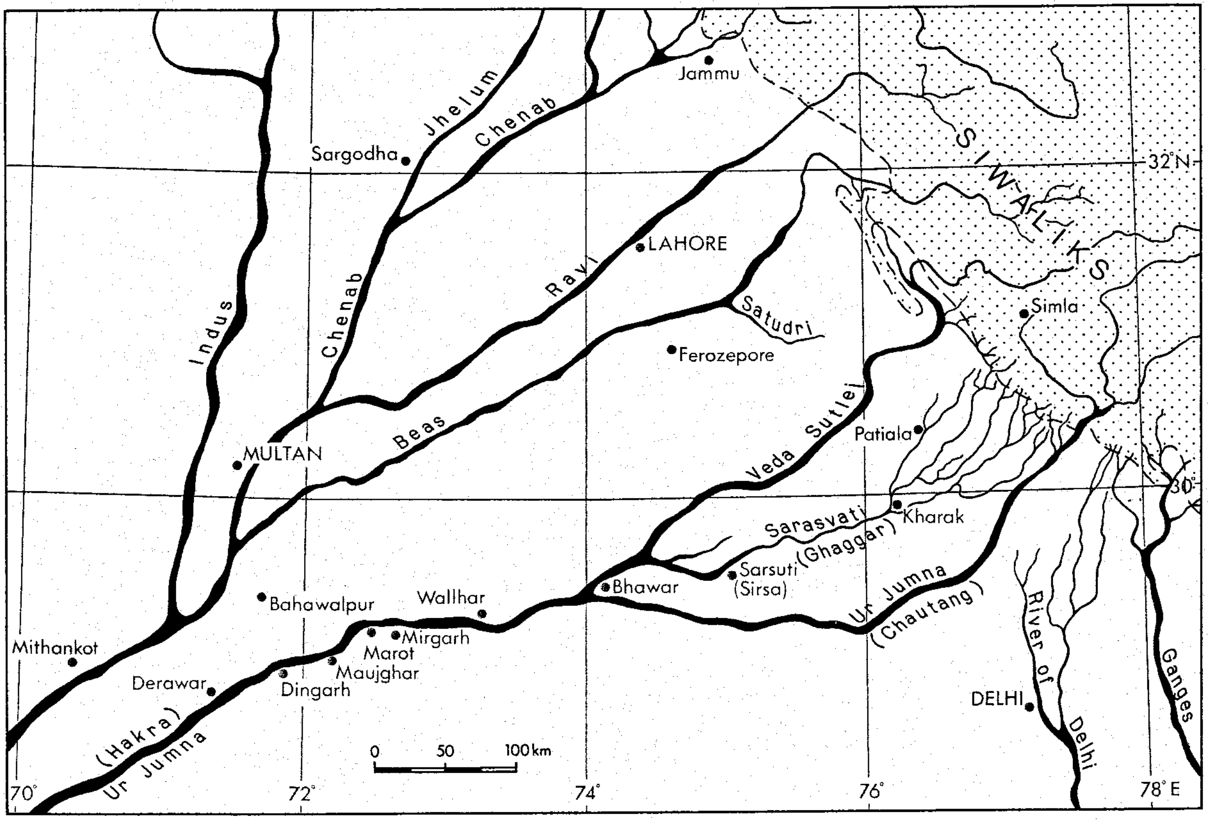

Fig. 10.15. The Indus River system around 2,000 BC (after WILHELMY 1969).

Around 1,500 to 2,000 BC the Jumna left the Indus system and joined the Ganges system. The upper part of the original Jumna was cut off from the higher precipitation of the Himalayas and their melt waters. The region formerly served by the Jumna

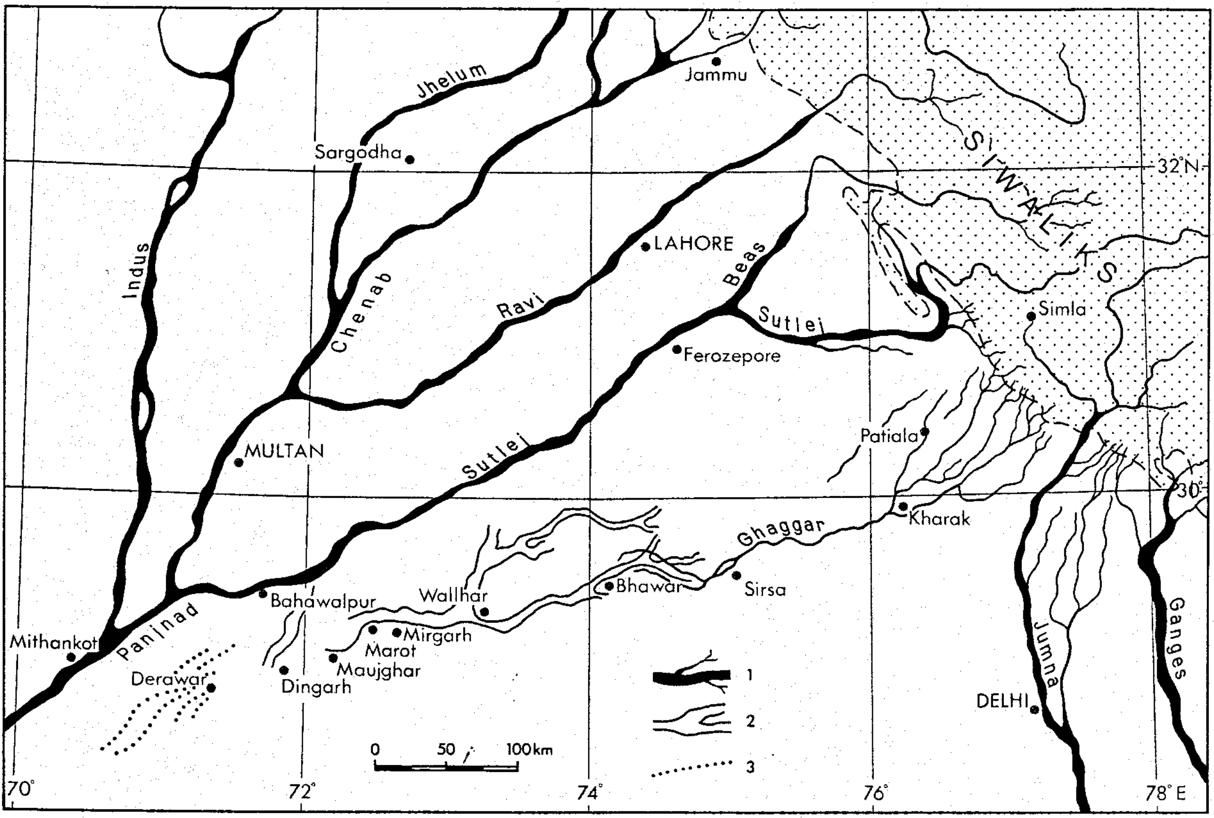

Fig. 10.16. The present Indus River system (after WILHELMY 1969); 1 = actual river courses, 2 = abandoned river beds, 3 = inland delta at Derawar.

began to dry up, and the ancient flourishing civilisation of the region was doomed. The (Hakra-) Sutlej still maintained its independence from the Indus River until about 600 BC. Around 500 BC to 1,100 AD the Sutlej joined the Beas River which flowed into the Chenab and lost its independence. All the area south of the Beas-Sutlej was left without major rivers; the only perennial rivers remaining in that area are the Ghaggar (Hakra) River and its tributaries, all originating in the foothills. Around 1,300 to 1,500 AD the Sutlej left the Beas River, returned back into part of his former bed and flowed into the Indus. Traces of abandoned river beds demonstrate that temporary flood flows from the Sutlej into the Hakra-Ghaggar system did occur.

The present situation is shown in Fig. 10.16. The Beas has ceased to exist as an independent river. It is now a short side branch of the Sutlej. With the original Jumna lost to the Ganges system and the Beas having been erased from the map as a major river the "Land of Seven Rivers" has been brought down to the "Land of Five Rivers",the Punjab.

The subsurface geology of Cholistan is comparable to that of the Punjab in every respect. Also the hydraulic properties of the aquifers as well as the hydraulic system are similar to those of the Punjab (Chapter 10.211). The striking difference is the existence of a huge lens of fresh groundwater about 70 km south of the Sutlej River. The lens is elongated in east-west direction and follows the line Abbas-Mojgarh/Januwali. Its length amounts to more than 90 km and its width to about 15 km (Fig. 10.17). Its

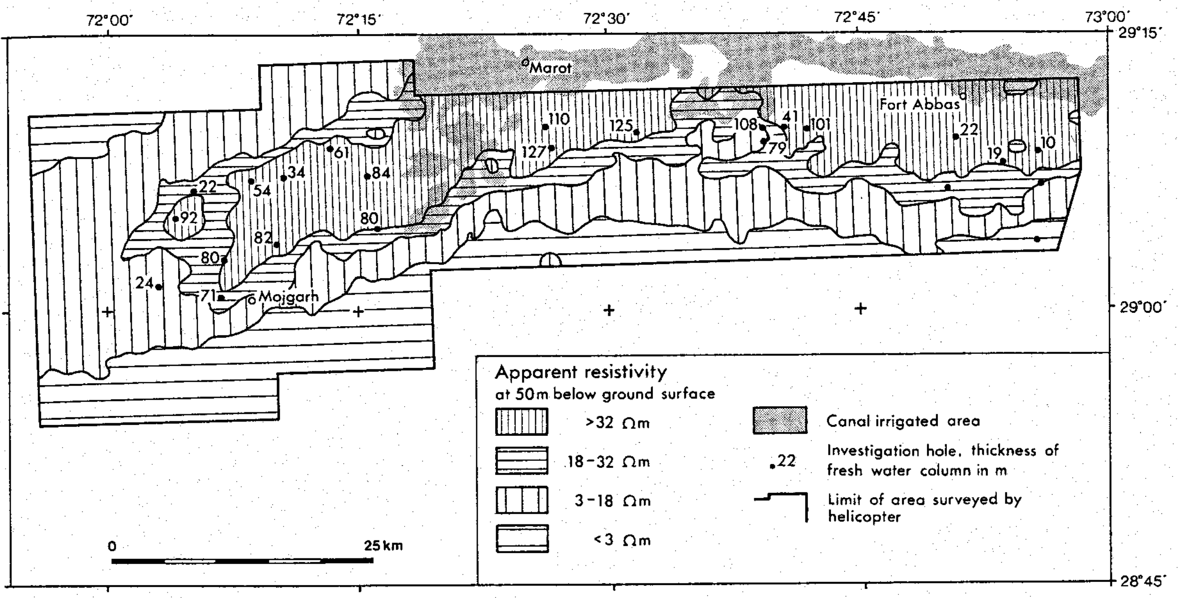

Fig. 10.17. The "Old Hakra" freshwater lens (after PLÖTHNER 1992). Areas with a resistivity of more than 32 Ωm indicate the occurrence of fresh groundwater, areas with 18–32 Ωm brackish groundwater, and areas with less than 18 Ωm saline groundwater. Areas with a resistivity of less than 3 Ωm contain highly saline groundwater.

maximum thickness is proved to be 120 m. This unexpected fresh groundwater lens was detected by hydrogeologic and geoelectric methods and delineated by a helicopter-borne electromagnetic survey in a BGR/WAPDA joint venture in the years 1986/87 (BENDER & KNOOP 1989; D. PLÖTHNER 1992). The location of the lens coincides roughly with the course of the "Old Hakra" and is certainly one of the last remnants of this lost river. It is thought that the lens no longer receives recharge and must be considered to be "fossil".

10.213 The lower Indus Valley

The lower Indus Valley extends from the confluent of the Sutlej with the Indus River southward for about 600 km to the coast of the Arabian Sea and from the Baluchistan Mountains in the west to the Thar Desert in the east. It covers about 60,000 km^2 and ranges in altitude from sea level to 110 m ab.s.l. The plain of the lower Indus is marked by numerous abandoned river beds and flood channels. Obviously the river activity is and has been concentrated at the flanks of the valley (Fig. 10.18). The western flank is occupied by the present course of the Indus. Along the eastern flank a distinct abandoned river bed is preserved which is called the (eastern) Nara. Between the two river courses south of Sukkur an outcrop of hard rocks occupies the middle of the river plain.

At Sukkur three conspicuous abandoned river beds branch from the present Indus course. One, called the western Nara, detours to the west and returns to the Indus bed south of Sehwan. Two others run east of the present Indus. Historians and geographers have identified these abandoned river beds as old Indus courses and have tried to date

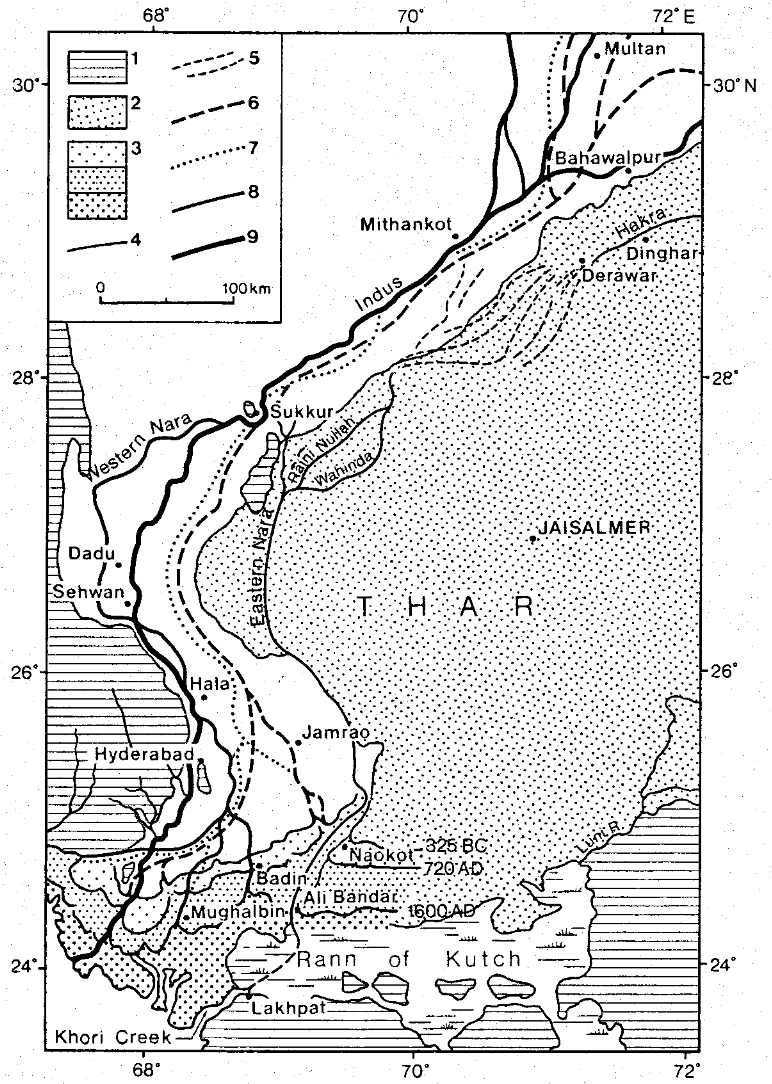

Fig. 10.18. The lower Indus Valley (modified after WILHELMY 1969). 1 = consolidated rocks; 2 = sand and dunes of the Thar Desert; 3 = coast lines in the years indicated (325 BC – campaign of Alexander the Great, 720 and 1600 AD Arab conquests); 4 = Hakra – Nara course; 5 = the inland delta at Derawar; 6, 7, 8, 9 = course of the Indus River: (6) during Alexander's time, (7) at the beginning of the Arab conquest, (8) in 1600 AD, (9) present.

the periods of their activities making use of evidences found in old literature. WILHELMY (1969) summarized their findings as represented in Fig. 10.18.

WILHELMY (1969) suggested that the Indus and Nara systems were separated most of the time and that the Nara represents the lower course of the Hakra (Chapter 10.22). The Nara and Hakra formed part of a separate independent river system (Sutlej – Hakra – Nara) which had its own mouth to the Arabian Sea, still indicated by the inlet at Kori Creek. The inland delta at Derawar is probably one of the last signs of old Hakra's activity (Fig. 10.18). The topographical lows abandoned by the streams are nowadays used again as water conduits by the irrigation system fed by the Indus.

Lithological logs of numerous boreholes published by NAZIR AHMAD (1974) suggest that the permeability pattern of the sediments of the lower Indus Valley is similar to that of the Punjab. In some of the boreholes the base of the aquifer system was tapped at about 350 m of depth. Moreover, the geohydraulic principles in the lower Indus Valley are the same as in the Punjab: Recharge to the aquifer system is provided by infiltration from the Indus River (influent nature); discharge occurs by evapotranspiration from groundwater.

The areal distribution of the salt content of the groundwater in the lower Indus Valley reflects the hydraulic system. Fresh groundwater is restricted to a strip about 15 km to 20 km wide along both sides of the river, more or less representing its flood plain.

10.214 Tharparkar

The Tharparkar Desert rises gently from the Rann of Kutch and the Indus flood plain towards northeast. Its higher elevations range between 60 m and 200 m. It covers an area of about 50,000 km^2. No rivers or streams exist in Tharparkar. Rainwater flows (mostly as sheet flow) to the nearest topographic low, and either evaporates there or infiltrates. The Tharparkar area is covered with sand of variable thickness. Stabilised dunes cover almost the entire area; drifting sand is rare. The interdunal valleys and also the lows between the parabolic dunes are vegetated with scattered scrub, bushes and small trees. Numerous interdunal valleys and lows between parabolic dune ridges contain rain-fed agricultural fields.

The eastern part of Tharparkar was investigated hydrogeologically and geophysically (geoelectrics and helicopter-borne EM-survey) in a joint WAPDA/BGR venture (BGR 1991). The investigations resulted in the delineation of two types of aquifers: Perched aquifers from 5 m to 45 m deep and an upper, medium-deep aquifer from 10 m to 140 m deep. In addition, a high-resistivity layer (50 m to 150 m) was identified at depths between 220 m and 320 m which may indicate the presence of a deep fresh-water-bearing aquifer.

The perched aquifers are situated in slight depressions, developed in sandy layers and friable sandstones. They are sealed underneath by layers of claystone or clay and characterized by a depth to the water table between 5 m to 15 m in the northern part and 30 m to 45 m in the western part of the area. Thickness is generally less than 5 m and extent is very limited.

The medium deep aquifer is developed in silty, fine to medium grained sand with a thickness ranging from 6 m to 26 m. Underneath this sand cover an alternating sequence of friable sandstone, hard, partly quartzitic sandstone, siltstone, clay-stone and shale is present. The depth to the water table in the medium-deep aquifer is around 100 m in the northern part of the area, 45 m to 140 m in the central part and 10 m - 40 m near the Rann of Kutch.

The perched aquifers contain mostly fresh groundwater (between 700 and 3,000 µS/cm) but show extreme variation in groundwater salinity over small distances. Groundwater in the medium deep aquifer is saline to highly saline showing EC-values of 3,000 to 20,000 µS/cm. Groundwater with less than 1,500 µS/cm is mostly from the sodium bicarbonate type, with increasing mineralization the waters turn to a sodium chloride type.

10.215 Quaternary sub-basins west of the Indus River

Two types of sub-basins belong to the Indus catchment area west of the Indus River: (1) basins surrounded by mountain ranges with narrow outlets to the Indus (Peshawar – Mardan Basin, Bannu Basin), (2) basins which represent lateral enlargements of the Indus Plain extending into the Baluchistan Mountains (Dera Ismail Khan Basin, Nasirabad Basin).

The **Peshawar – Mardan Basin** occupies a plain which is about 80 km x 120 km wide and is surrounded by the ranges of Kohat (south), Khyber (west) and Swat (northeast). The plain is watered mainly by the perennial Kabul and Swat Rivers and in the east by the Indus. A total of about 340,000 ha of land is irrigated from the Warsak reservoir on the Kabul River and from barrages which divert water from the Kabul, Swat and some smaller rivers (SCHOLZ 1985). Groundwater is present in the more than 300 m thick Quaternary basin fill which consists of silt, sand and gravel with intercalations of clay. The unconsolidated material is ill sorted and generally not of high permeability. Some deep (approx. 300 m) boreholes tapped artesian groundwater in gravel layers in the western part of the basin. According to NAZIR (1974), groundwater quality in the area is generally satisfactory.

The **Bannu Basin** covers an area of about 8,000 km². It is surrounded by relatively low mountain ranges formed by Eocene and Miocene rocks. The Kurram River and its tributary the Gambila flow through the plain and provide water for irrigated agriculture. The Quaternary basin fill, which is at least 400 m thick, consists mainly of piedmont deposits which are of relatively low permeability. The rivers are of influent nature for the upper part of the aquiferous zone. Depth to groundwater amounts to about 100 m far away from the rivers. Near the rivers groundwater is found to be artesian at greater depth. NAZIR (1974) states that groundwater quality is generally satisfactory in the Bannu Basin.

The **Derajat Basin** extends northward for about 330 km from 29° to 32° 30' latitude between the Indus River on the east and the Sulaiman Range on the west. The basin underlies a plain that is 100 m to 300 m above sea level; the adjacent mountains rise 1,000 m to 2,000 m above sea level. Numerous rivers and creeks enter the plain from the west and northwest but most of them dry up during the hot period. Three rivers are perennial and supply the irrigation water for the upper parts of the plain. From north to south these are the Tank Zam, the Gumal River and the Khora River. Their drainage areas and their measured discharges are listed in Table 10.10.

Table 10.10. River discharge (average 1960-63) and catchment areas of the Derajat Basin (after HOOD et al. 1969).

river	discharge (10^6 m^3/a)	catchment area (km^2)
Tank Zam	185	2,176
Gumal	416	29,008
Khora	40	1,119

Physiographically the Derajat Basin may be divided into several north-trending provinces. Along the Indus River is an active flood plain about 5 km wide. To the west is a strip 10 km wide that is considered to be an abandoned flood plain in the northern part and has been identified as a "high level terrace" in the southern part (HOOD et al. 1969). This terrace is probably an equivalent of the bar uplands in the Punjab. West of this strip is a piedmont plain 50 km wide. This plain is covered with detrital material that is coarser grained near the adjacent mountains from which it derived. In the northern part, the piedmont plain is mostly covered by aeolian deposits in the form of barchan dunes. Talus fans of boulders and gravelly material are along the west edge of the plain, against the mountains.

The Baharpur canal branches off the Indus River as an inundation canal commanding about 40,000 ha. Because it can convey water only during high flood stages, only about half of the irrigable land is under cultivation for most of the time. In addition, about 20,000 ha are watered by direct inundation (sailab) in the active flood plain of the Indus.

Small patches of land are irrigated by water from karezes or from the perennial flow of the larger rivers (Kalapani) at the western and northwestern rim of the piedmont. About 100 - 200,000 ha of the Dera Ismail Khan District are rainfed farmland where flood run-off from mountain streams (rud Kohi) is also utilized.

Groundwater-bearing strata are irregularly distributed in the unconsolidated sedimentary fill of the Derajat Basin. Groundwater is most abundant in the piedmont along the west side of the basin, and in the sandy fan deposits. More permeable strata can be expected near the Indus.

The sedimentary sequence in the basin is best known in the D. I. Khan District from about 30 testholes which were thoroughly logged (HOOD et al. 1969). The deepest holes reached a depth of about 500 m. Boreholes sunk near the Indus River perforated relatively pure sands as much as 400 m thick. Further to the west intercalations of silt and clay become successively more abundant. Coarse material was tapped near the mountains. A so-called "thick clay" interval, which does not contain any considerable sandy material, forms the base of the aquifer system. The top of the "thick clay" rises from east to west and to northwest (Fig. 10.20). Thus the thickness of the aquiferous zone ranges from 300 m in the east to 200 m in the west.

Depth to the water table ranges from about 30 m at the foot of the mountains to 3 m or less near the Indus. In most of the area it is around 10 m to 20 m. At greater depth the groundwater can be under artesian pressure (observed hydraulic head: at about 7 m above land surface). The groundwater table slopes from about 300 m above sea level in the west to 165 m in the east, with a mean gradient of approx. 2.5 : 1,000. Near the Indus River, the slope of the groundwater table is directed westward away from the river. Where the two directions meet, a closed depression in the groundwater table has formed (Fig. 10.19).

Hydraulic parameters are known from 11 pumping tests. The results reflect the characteristics of the aquifer system (Table 10.11).

The hydraulic system of the basin is shown schematically in Fig. 10.20.

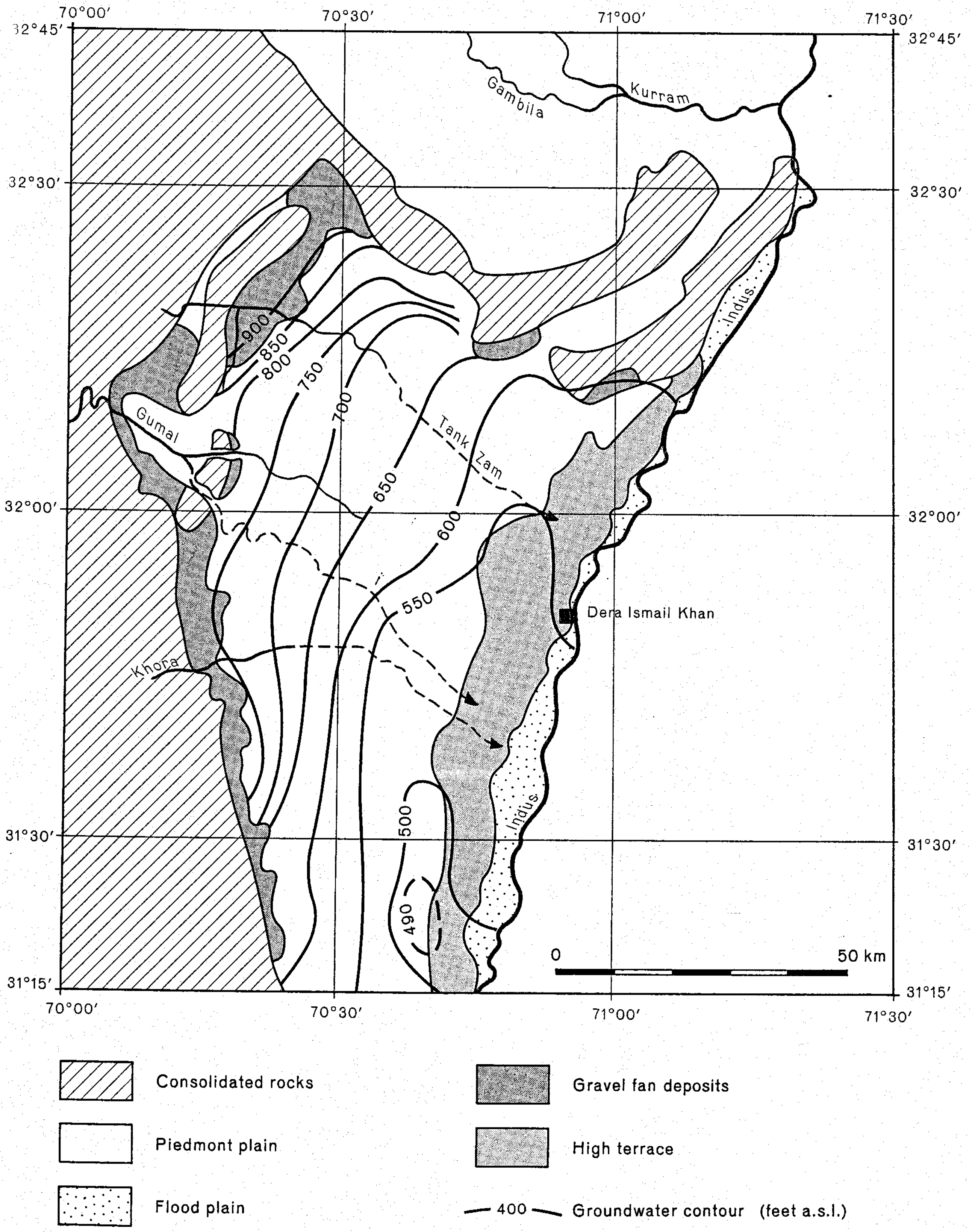

Fig. 10.19. Groundwater table, northern part of Derajat Basin (after Hood et al. 1969).

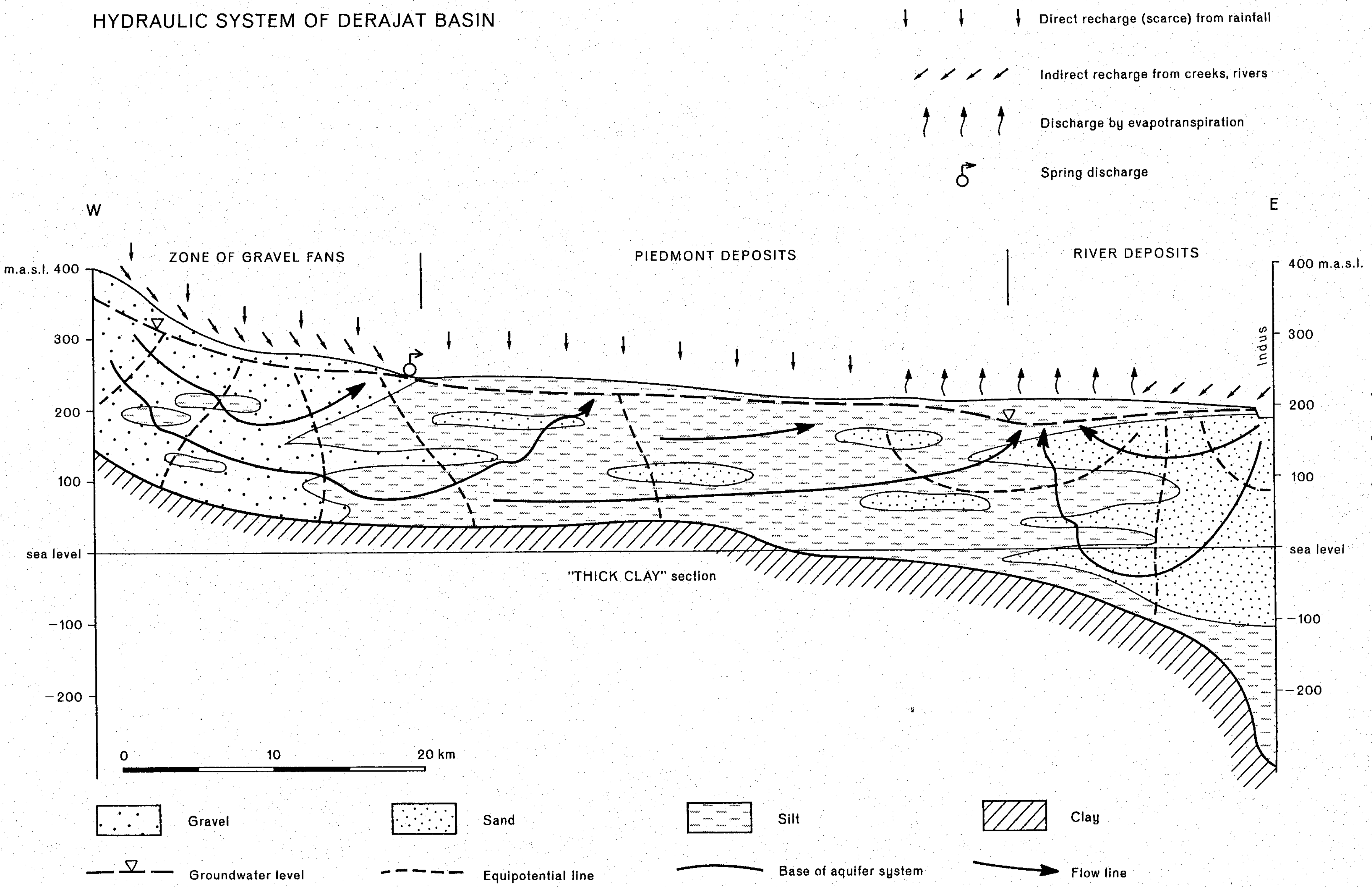

Fig. 10.20. Hydraulic system of Derajat Basin (modified after HOOD et al. 1969).

Table 10.11. Hydraulic data of the Derajat Basin.

	Permeability (m/s)		Transmissivity (m^2/day)		Specific capacity (m^3/h/m)	
	max.	min.	max.	min.	max.	min.
GF (3 tests)	$2.1 \cdot 10^{-3}$	$3 \cdot 10^{-4}$	4,858	472	6.6	0.7
PP (4 tests)	$3.1 \cdot 10^{-4}$	$9.6 \cdot 10^{-6}$	1,203	36.7	0.5	0.2
IR (4 tests)	$7.6 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	3,913	1,689	10.2	4.6

GF = zone of gravel fans; PP = piedmont plain; IR = zone of influence of the Indus River

Direct recharge from rainfall is negligible. Recharge to the system occurs almost exclusively as indirect recharge from influent rivers, in the west and northwest from the rivers and creeks entering the plain and infiltrating in the area of the gravel fans, in the east from the Indus River as line recharge from its bed and as areal recharge in its flood zone.

Groundwater movement within the system is determined by the arrangement of the recharge zones which surround the basin and by the spatial distribution of permeable strata within the aquifer system, being almost equally permeable in the east and west but with a broad area of considerably lower permeability in between. At the transition zone between the western high permeable and the central low permeable areas a small portion of the groundwater leaves the system as spring discharge. This spring water is being used for irrigation, and most probably has been used in this way since the early days of agriculture. In times of water shortage the discharge quantities have been enhanced by the construction of karezes.

Inasmuch as the basin is completely surrounded by recharge zones, groundwater can leave it only by evapotranspiration, a fact that is exemplarily documented by the existence of a closed depression in the groundwater table which has developed at the lower end of the Dera Ismail Khan District.

The Nasirabad (Kachhi) Basin is defined as follows:

This basin constitutes the most conspicuous extention of the Indus lowlands toward the northwest. The basin forms a triangular plain of about 16,000 km² in area and elevated 100 m - 200 m ab.s.l., flanked by mountain ranges of about 1,000 m in altitude with rocks of Early Tertiary age in the west and northeast, and bordered in the east by the middle terrace of the Indus Valley. The plain is built up by detrital material derived from the surrounding hills.

Numerous small rivers and creeks enter the plain from the mountains but none of them reaches the Indus River. They seep into the underground or evaporate. One of the bigger rivers entering the plain is the Nari. Its permanent run-off is totally used for irrigation at Sibi. Its flood waters are partially diverted by temporary earthern embankments in the central part of the plain.

According to WAPDA (1986), depth to groundwater ranges from 3 m to 25 m in the basin. WAPDA indicated that an amount of $72 \cdot 10^6$ m^3/a of groundwater of drinking water quality is estimated to be extractable on a safe yield basis. Groundwater occurs generally under water table conditions.

10.216 Basins of the Indus catchment area in Baluchistan

Almost all river courses in Baluchistan are influenced and determined by tectonic structures. They commonly follow active tectonic depressions which are filled with Quaternary deposits. These deposits form porous aquifers with a substantial capacity for underground storage and drainage of water.

Following are brief descriptions of Baluchistan river basins which are within the Indus catchment area (WAPDA 1986).

With a total drainage area of 13,857 km^2, the **Zhob River basin** is drained by the Zhob River. It comes from an altitude of about 3,000 m near Muslimbagh, flows mostly northeast over a length of 386 km to its junction with the Gumal River, which then enters the plain of Dera Ismail Khan (Derajat), and finally joins the Indus. The Zhob River becomes a perennial river 72 km from its source. Its water is used for irrigation.

In its upper course, the valley opens to a trough 125 km long and 10 km to 15 km wide, which is filled with Quaternary deposits. A groundwater body, which is under water table conditions, has developed in these deposits. The depth to groundwater ranges between 125 m in the piedmont and 10 m at the valley floor. The groundwater potential of the Zhob River basin has been estimated to be $110 \cdot 10^6$ m^3/a (as safe yield).

The **Nari River basin** with a total drainage area 21,510 km^2 is drained by the Nari River, also known under the names Anambar, Beji and Loralai. The river has a total length of 482 km. Along its course the Nari River valley opens at several places to large, elongated "troughs" which are filled with unconsolidated Quaternary deposits, thus forming sub-basins prospective for groundwater exploitation. Two conspicuous sub-basins formed within young tectonic structures are parts of the Loralai and the Gumbaz Valleys. The Gumbaz Valley is an east-trending grabenlike structure 80 km long and about 100 km wide. This sub-basin is crossed almost perpendicularly by the Nari (Ahambar) River, which has an average run-off of $133 \cdot 10^6$ m^3/a before leaving the basin. The Quaternary basin-fill consists of sand and gravel with clay and silt beds. The maximum thickness of the Quaternary exceeds 270 m.

Groundwater is generally under water table conditions in this basin, but was found to be artesian (2 flowing wells) at the center of the basin. Depth to groundwater is generally around 15 m to 20 m. WAPDA/UNDP (1986) have recently estimated the extractable potable ground-water resources of the Nari River basin to be $106 \cdot 10^6$ m^3/a. Recharge is accomplished from rainfall and river floods, discharge happens as base flow, spring flow and by evapotranspiration. Recharge is estimated to be in the order of $265 \cdot 10^6$ m^3/a. This figure is counterchecked by an estimate of discharge from the system which amounts to $247 \cdot 10^6$ m^3/a. Aquifer characteristics based on 7 pumping tests show transmissivity ranges from 6,000 to 88,000 m^2/d; specific capacity from 28.6 to 155.7 m³/m/h; and a specific yield of 16 %. The chemical quality of the groundwater encountered is variable. Values of total dissolved solids range from 800 to 5,200 ppm.

The **Mula River basin** has a total drainage area of 4,227 km², 932 km² of which is covered with alluvium. The basin is crossed by the Mula River, which has a total length of 290 km and drains the northeastern part of the Jhalawan Mountains, and also the southwest corner of the Kachhi Plain.

Wherever possible the small perennial river flow is drawn off to irrigate arable land along its course, while flood water is utilized for cultivation in the Kachhi Plain.

The alluvial sequence consists in this basin of gravel, sand, silt and clay, and its thickness ranges from 30 m to 230 m in the areas investigated. Groundwater is under water table conditions. Depth to groundwater ranges from a few meters to 80 m. Groundwater movement is directed from the valley flanks to the Mula River which is of effluent nature. Recharge to groundwater was estimated to be $68 \cdot 10^6$ m³/a and was found to be balanced by natural and artifical discharge.

Aquifer characteristics, based on the results from 8 pumping tests are as follows: Transmissivity ranges from 414 to 27,600 m²/d, permeability ranges from $1.4 \cdot 10^{-4}$ to $6.5 \cdot 10^{-3}$ m/s; and porosity averages 22.5 %. Chemical quality of the groundwater is good to excellent (250 to 950 ppm total dissolved solids).

The **Gaj River basin** has a total drainage area of 6,863 km² of which 1,761 km² is covered with alluvium. The alluvial deposits range from gravel to clay and are around 130 m thick. Depth to groundwater ranges between 7 m and 90 m. The groundwater potential is estimated to be $61.8 \cdot 10^6$ m³/a, $21.2 \cdot 10^6$ m³/a of which is presently being utilized for irrigation and domestic purposes. $40.6 \cdot 10^6$ m³/a is being discharged by evapotranspiration and run-off.

10.217 The Potwar uplands (Rawalpindi)

are defined as follows:

They represent a hilly plain with elevations mostly between 200 m and 500 m ab.s.l. with some hills surmounting 500 m ab.s.l. They cover an area of about 100 km x 150 km and are bordered in the north by the Himalayan foothills, in the east by the mountains of Kashmir, in the south by the Salt Range, and in the west by the Indus River.

The Potwar uplands are drained by the Indus River in the west and the Soan River with its numerous tributaries. The Soan River crosses the uplands diagonally.

The underground of the area consists mainly of Miocene/Pliocene sedimentary rocks (sandstones, conglomerates and thick sequences of mudstones) with relatively small patches of Quaternary deposits.

Groundwater resources are limited in the Potwar by low permeability of the aquifers and unfavorable recharge conditions, in spite of the relatively high rainfall of the area, recharge is hampered by the existence of clayey toplayers on the alluvial deposits and by the steep topographical gradients of the area which accelerate run-off.

10.22 The Makran Coast catchment area

The Makran Coast catchment area covers about 107,500 km^2. Its borders run mainly along the crests of the central Makran Range in the north and the northwest, and along the Kirthar Range in the east; the southern limit is naturally given by the coast of the Arabian Sea; the limit to the west is arbitrarily taken as the international border with Iran.

The drainage pattern of the Makran area is strongly influenced by the folded and faulted Tertiary rocks which crop out in west-trending structures over much of the area. In the western part, river courses are in the tectonic lows (grabens and synclines) over long distances. Toward the east they follow the changing strike of the mountain chains and run first to the northeast and finally, in the extreme eastern part of the Makran Coast catchment, from north to south.

Groundwater bodies are known to exist in the Quaternary sediments that fill the valleys and form coastal deposits. The coastal Quaternary consists mainly of silt and silty clay deposits, with interbedded layers of sand and gravel which are most extended where the coastal plain is traversed by the rivers. The Quaternary deposits in the valleys are generally of coarser material.

Generally the groundwater in the Makran catchment is only slightly mineralized, but at places the mineral content is raised by evapotranspiration of groundwater, and in the zone of sea water intrusion along the coast the groundwater is highly saline.

The main hydrogeological characteristics of the more prominent river basins in the Makran catchment are described below. Where not otherwise indicated, the information is taken from WAPDA (1986).

10.221 Porali River basin

The principal effluents of the Porali River (length 281 km) are Kud, Tibbi and Lohandar. The Porali has been identified as the ancient River Arabia or Arabius. After leaving the mountains the Porali flows through a wide, partly swampy plain (Bela Plain) in which it bifurcates about 50 km before entering the Somniani Bay on the Makran Coast. The axis of the Porali River basin coincides with the core of the faulted Lasbela anticline in which some of the older rocks (Jurassic and Cretaceous) of Baluchistan are exposed. The Quaternary sediments, which contain the main aquiferous zone, are fine to coarse grained deposits typical of Baluchistan valleys. Promising aquifers are associated with alluvial fans, piedmont slope deposits and river channels.

Hydraulic parameters are known from 28 pumping tests as follows: Transmissivity: max. 435 m^2/d; specific capacity: 0.7 to 1.4 m^3/h/m; porosity: average 13 from pumping, 33 % from laboratory tests.

The groundwater budget is estimated as follows: $273 \cdot 10^6$ m^3/a of groundwater is lost to evapotranspiration, and $17 \cdot 10^6$ m^3/a as surface and surface outflow; the groundwater available for further development is estimated to be $138 \cdot 10^6$ m^3/a. With the exception of the zone of evapotranspiration from groundwater in the Bela Plain and the zone of seawater intrusion at the coast all groundwater is of good quality.

10.222 Hingol River basin

The Hingol is the largest river in Baluchistan (length 565 km). It has no continuous flow in its upper part but becomes perennial from Jau onward, about 140 km from its mouth. Testholes (106 drilled) reveale that the Quaternary valley fill is as much as 200 m thick. Groundwater budget of the basin is estimated as follows: Recharge: $355 \cdot 10^6$ m^3/a; discharge by evaporation and evapotranspiration: $285 \cdot 10^6$ m^3/a; discharge by artificial extraction: $70 \cdot 10^6$ m^3/a.

10.223 Dasht River basin

The Dasht River system is one of the conspicuous examples of tectonically bounded rivers of Baluchistan. Its main effluents are the Nishing, which comes from the west, and the Kaur, which comes from the east. Their waters merge and form the Dasht River which then heads southeast to its final destination, the Gwatar Bay.

The results of testholes (55) show that the thickness of the Quaternary of the basin exceeds 200 m. The groundwater budget of the basin is estimated as follows: Recharge: $135 \cdot 10^6$ m^3/a through precipitation, $28 \cdot 10^4$ m^3/a from irrigation; utilization: $71 \cdot 10^6$ m^3/a; discharge: $92 \cdot 10^6$ m^3/a by evapotranspiration.

10.23 The Kharan Desert catchment (enclosed drainage basins of Baluchistan)

The Kharan Desert catchment covers a huge area of about 200,000 km². It belongs to a vast area without any superficial outflow, which stretches from Baluchistan through central Iran into Turkey. Within that zone numerous closed basins have developed. Groundwater flow, as well as run-off, ends in every individual closed basin in mud flats where water discharges from the basin by evaporation and evapotranspiration, leaving behind its dissolved matter in the form of evaporites. Three individual closed basins have formed in the Kharan catchment: the Hamun-i-Mashkael, the Hamun-i-Lora and the Garkap Salt Swamp. The waters at the northern side of the Koh-i-Sultan Mountains and the Chagai Hills head towards Afghanistan for the Gand-i-Zirrah and the Helmand River.

10.231 Hamun-i-Mashkel Basin

This closed basin, which has a total drainage area of 83,500 km², is the largest one in Pakistan. The area of its Quaternary basin fill amounts to approximately 52,000 km². It is extremely arid, with large dune covered areas and an extended mud flat contacting salt deposits at its center. In contrast, the surrounding mountains, as the Chagai Hills and Rashkoh Range in the north and the Siahan Range in the south, rise to altitudes of about 3,000 m and give rise to several perennial rivers. These are mainly in clockwise succession: The Mashkel (coming from Iran and meeting its 250 km long tributary Rakhshan at the border), the Baddo Rud, the Morjen and the Shikar River.

The groundwater conditions of the basin are not well known. More intensive hydrogeological work has been carried out in the area of the Baddo Rud (SHEIKH, M. Y. 1986). The Quaternary fill of the Baddo Rud sub-basin exceeds 200 m in thickness and is composed of clastic sediments ranging from gravel to clay.

Hydraulic parameters of these sediments are known from 16 pump tests: Transmissivity values range from 26 to 11,400 m^2/d but most are in the order of 2,500 to 6,200 m^2/d; hydraulic conductivity (as related to screen length) is around $1 \cdot 10^{-4}$ m/s; porosity is determined to be 25 % as an average.

The Baddo Rud is of effluent nature in the upper half of its course with a distinct perennial base flow of $4 \cdot 10^6$ m^3/a. The groundwater table has a gentle gradient of about 1/1,000 in this area. Recharge derives from rainfall and from numerous small creeks which seep underground in the piedmont area.

The groundwater balance of the Baddo Rud sub-basin is estimated as follows:

Discharge			
base flow		4	$\cdot 10^6$ m^3/a
spring discharge		0.45	$\cdot 10^6$ m^3/a
karezes discharge		0.45	$\cdot 10^6$ m^3/a
abstraction from dug wells		2.2	$\cdot 10^6$ m^3/a
abstraction from tube wells		3.6	$\cdot 10^6$ m^3/a
evaporation and evapotranspiration		24.1	$\cdot 10^6$ m^3/a
total	approx.	34.8	$\cdot 10^6$ m^3/a

Recharge is estimated to be in the same order of magnitude. The measured electrical conductivity ranges from 1,000 to 3,000 micro S/cm (102 samples).

10.232 Hamun-i-Lora Basin

The main river of the Hamua-i-Lora Basin is the Pishin Lora having its source in the Toba-Kakar Range not far from Quetta. It runs for about 400 km, partly in Afghanistan territory, and ends in the Hamun-i-Lora salt and mud flat. No hydrogeological data on this basin are available.

10.3 Groundwater in consolidated rocks

Little work has been done on the availability and characteristics of groundwater in the consolidated rocks in Pakistan. An appraisal of the groundwater resources potential in consolidated rocks in the Daddu, Thatta and Karachi districts was published by ANISUDDIN et al. (1985). The Tertiary sedimentary strata in many areas have hydraulic properties as compiled in Table 10.12.

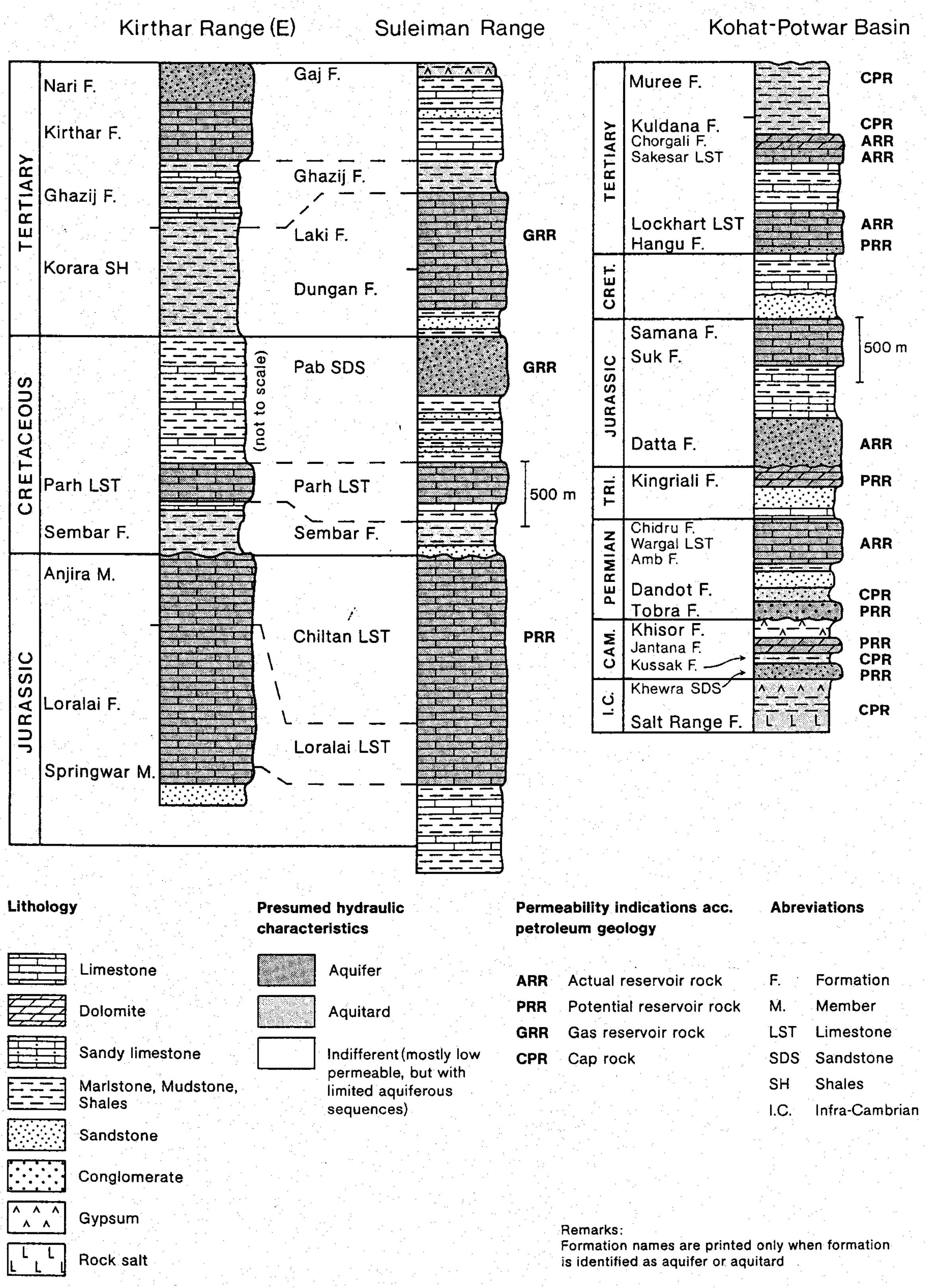

Fig. 10.21. Tentative permeability pattern of the sedimentary sequence of the Indus sedimentary basin (by courtesy of and communication with Dr. PORTH and Dr. REIMANN, Petroleum-geologists, BGR, Hannover).

Table 10.12. Hydraulic properties of Tertiary rocks in western Sindh.

Age	Formation	Hydraulic properties
Pleistocene to Pliocene	Manchar	Intercalated mudstones and sandstones; contains a few beds of conglomerate, which show high porosity and permeability.
Miocene	Gaj	The upper part consists of interbedded mudstones, limestones and rarely sandstones; the lower part consists of well jointed, bedded, karstified limestones; sandstones and especially the lower limestones are aquiferous.
Oligocene	Nari	Aquiferous in the upper part of the formation which contains medium to coarse grained, porous sandstones.
Eocene	Tiyon	Mostly limestone of a crystalline, compact nature, acts as an aquitard.
Eocene	Laki	Limestone interbedded with marls, aquiferous only where fractured and karstified; varying well yields to be expected.

In general, aquiferous zones can be found in consolidated sedimentary rocks of clastic or carbonate nature if a sufficient permeability is provided either by preserving the original permeability of the porous space (e. g. in coarse- to medium- grained clastic sediments), or by fracturing as a result of tectonic stressing. In carbonate rocks the fractures (joints, fissures, cracks) can further be widened by solution, i. e. the rocks can be karstified. Karstification can result in permeabilities which are comparable to, or even greater than, those of loose sands.

Based on the lithological desription of the sedimentary sequence and the classification of strata as reservoir rocks and cap rocks (Chapter 7.1), a tentative permeability pattern of the Indus sedimentary basin is shown in Fig. 10.21.

10.4 Thermal springs

SHUJA (1986) correlated tectonic and geologic features with surface manifestations of thermal springs to delineate geothermal areas. The distribution of thermal springs reflects the major geotectonic features, as the underthrust of the Arabian and the Indian Plate with the Eurasian Plate, and the structural zone between the Arabian and the Indian Plate. Hot springs are found in the Himalayan collision zone, in the Chagai volcanic arc and at the Indus basin marging (Fig. 10.22).

In the Himalayan collision zone the Main Mantle Thrust and the Main Karakorum Thrust obviously are the geotectonic elements aiding geothermal activity which appears at the surface in the form of thermal springs in the Chitral, Gilgit, Hunza, Yasin and Skardu valleys. Surface temperatures of these springs range from 20 to 91 °C, the hottest ones being found at Murtzabad. Subsurface temperatures of springs in Gilgit and Hunza have been estimated to range from 83 to 252 °C based on the silica geothermometer, and from 85 to 252 °C based on the Na-K geothermometer.

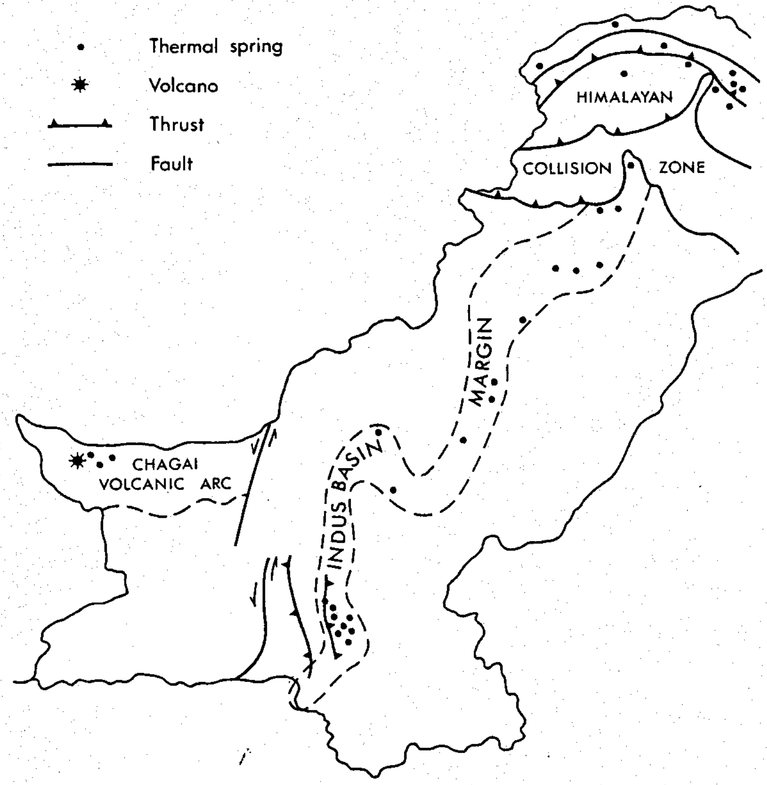

Fig. 10.22. Thermal springs (after SHOUJA 1986).

In the **Chagai volcanic arc** thermal springs are found in the surrounding of volcanic cones as the Koh-e-Sultan volcano. Hot groundwater has also been tapped by boreholes. Surface temperatures of the springs range from 27 to 39 °C. The waters contain silica at a content of 33 to 183 ppm. Most of the springs contain H_2S gas and show salt (also rarely sulphur) precipitation at their outflow.

Thermal springs at the western **margin of the Indus Basin** (i.e. at the rim of the Sindh, Baluchistan and Salt Range mountains bordering the Indus Plain) seem to occur along faults and probably are the result of deep circulating meteoric water. Their largest concentration is found in the Dudu District (Sindh Province). High surface temperatures are reported from the springs at Lakhi (40 °C), and at Manghopir near Karachi (48 °C). In the Salt Range the temperatures of spring water range from 25 to 32 °C.

11. Soils

(FRANZ H. GRÜNEBERG)

About 55 % of Pakistan's labour force is employed in agriculture, producing 30 % of the nation's gross income. Thirtyfive percent of Pakistan's foreign exchange is earned by export of agricultural products, mainly rice and cotton (PAASCH 1987).

Of the country's total area (79.6 mio ha), 25 % consists of high mountains hardly suitable for agricultural production. 16.3 mio ha are cultivated. In general, the cultivated areas are located in arid and semiarid zones requiring supplemental water supply by irrigation. 12.7×10^{10} m^3 water, which is almost 3/4 of the estimated total river flow, are used for irrigation (AKRAM 1986).

11.1 Effects of environment on soil formation

Climate, geomorphology, bedrock, time, biological processes and human activity are the principal factors causing the alteration of rock into soils. In Pakistan, the effects of climate, relief, vegetation and soil management are stronger on the development of the pedon than those of bedrock or time.

11.11 Climatic factors and soil development

Pakistan lies in the transitional zone between the East Asian Monsoon-climate and the Mediterranean climate, characterized by winter cyclones (DICHTER & POPKIN 1967). In summer, moisture-loaded air masses from the Arabian Sea meet the hot and dry continent in southern Pakistan and are heated up. Before these air masses reach the northern mountains there are few natural barriers which might force them to ascend, cool down and precipitate their moisture load. No substantial rainfall occurs, therefore, in the Indus Plain. The southern slopes of the Himalayas, as well as parts of the border mountains in northwestern Pakistan have the benefit of the air moisture transported from the Arabian Sea. These air masses meet the Bengal branch of the Southwest Monsoon, which passes along the southern flank of the Himalayas (VESELIND & MCCURRY 1984). This results in comparatively high rainfall in the Hazara District.

Climatic factors measured above ground, however, affect soil dynamics only indirectly. Soil development is the consequence of physical, chemical and biological transformations occuring simultaneously in the soil material. These transformations are controlled by the **Soil Moisture Regime** (Table 11.1) and the **Soil Temperature Regime** (Table 11.2).

Table 11.1. Soil Moisture Regime (SMR; after US Soil Survey Staff (1975), pp. 51–57).

S M R	Soil Moisture Control Section		remarks
	dry	moist	
aquic	——	all pores in capillary fringe are filled by water	reducing conditions; no oxygen
aridic/ torric	a. > 50 % of time when S. T. is > 5 °C	b. < 90 consecutive days when S. T. is > 8 °C	evaporation greater than rainfall
xeric	a. > 45 consecutive days within 4 months following summer solstice	a. < 45 consecutive days within 4 months following winter solstice b. > 50 % of time when S. T. is > 5 °C c. > 90 cumulative days when S. T. is > 8 °C	thermic STR
ustic	a. > 90 cumulative days b. > 90 cumulative days	a. > 180 cumulative or > 90 consecutive days b. > 50 % of time when S. T. is > 5 °C	hyperthermic STR thermic STR
udic	< 90 cumulative days	> 45 consecutive days within 4 months following summer solst.	evaporation less than rainfall

Table 11.2. Soil Temperature Regimes (STR) (STR; after US Soil Survey Staff (1975); pp. 62-63).

S T R	mean annual soil temperature at 50 cm below surface	difference between mean winter and mean summer soil temperature
pergelic	0 °C or less	——
cryic	0 °C – 8 °C	——
frigid*	< 8 °C	> 5 °C
mesic*	8 °C – 14.9 °C	> 5 °C
thermic*	15 °C – 21.9 °C	> 5 °C
hyperthermic*	≥ 22 °C	> 5 °C

*) STR which differs between mean summer/mean winter soil temperature by < 5 °C (Iso) does not occur.

The water content of a soils Moisture Control Section (MCS)[1] during certain periods governs the Soil Moisture Regime (SMR).

The Soil Temperature Regime (STR) results of the mean annual soil temperature at 50 cm below surface, and the difference of the mean soil temperature of the 2 hottest and the 2 coolest months.

The US Soil Taxonomy (US Soil Survey Staff 1975), which is also applied by the Pakistan Soil Survey, takes into consideration these data.

A mathematical model developed by NEWHALL (1972) rendered it possible to compute the Soil Moisture Regime and the Soil Temperature Regime for a given region from the meteorological data. VAN WAMBECKE (1985) computed both regimes for South Asia and Southeast Asia, including data on 47 stations in Pakistan.

The **Hyperthermic Soil Temperature Regime** (Table 11.2) was calculated for 36 stations located in the Indus Basin, the Punjab, the Bannu-, and the Peshawar Basins. If sufficient soil moisture is available, the high soil temperature accelerates all chemical and biological processes in the soil.

The foothills north of Rawalpindi and the western highlands around Quetta represent a zone of **Thermic Soil Temperature Regime** (Table 11.2).

In addition, VAN WAMBECKE (1985) delineated zones of **Mesic** and **Cryic Soil Temperature Regimes** in the northern mountains, where vegetation and soil development are restricted to a few summer months.

High soil temperature and low precipitation during the summer results, in most of the country, in a Soil Moisture Control Section with plant-available water for less than 90 consecutive days. These conditions, known as **Aridic Soil Moisture Regime**, reduce the chemical transformation of soil material, limit the activity of soil organisms, and stop the production of organic matter substantially. Soil development under these conditions is very weak. The dominant process of soil dynamics is the upward-directed capillary movement of soil water due to evaporation at the soil surface and, consequently, the accumulation of soluble salts in the uppermost soil layers.

In northern and northwestern Pakistan, affected by the winter-cyclones of the Mediterranean climate, rainfall occurs predominantly during the cool season, when vegetation is dormant. As far as there is no frost, infiltration of the soils in the winter rainfall areas will be higher than in areas having equal summer rainfall. Therefore, under the Xeric Soil Moisture Regime, soil development will be deeper than under the Aridic Soil Moisture Regime.

The **Ustic Soil Moisture Regime** prevails as well under the Hyperthermic as under the Thermic Soil Temperature Regime. If the Soil Temperature Regime is hyperthermic, the Soil Moisture Control Section contains plant-available water during 180 cumulative days or at least 90 consecutive days; in the Thermic Soil Temperature Regime, the Soil Moisture Control Section contains plant-available water for at least half of the time when soil temperature is > 5 °C. The Ustic Soil Moisture Regime makes farming possible solely during the rainy season. During the dry season, irrigated farming is required as practised in the Potwar Plateau, and in the Punjab and the Peshawar Basins.

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[1] The upper boundary of the MCS is the depth to which a dry soil will be moistened by 25 mm water within 24 hours. The lower boundary is the depth to which a dry soil be moistened by 75 mm water within 48 hours.

Intensive wetting and plant available soil moisture throughout the year characterizes the **Udic Soil Moisture Regime**, which is observed only for Murree Station in Hazara District.

11.12 Geomorphological features and soil development

By interpretation of aerial photographs, MIAN & SIAL (1986) differentiated 9 land types within the Himalayas, the Indus Basin and the Indus estuary; these land types include various landforms.

Mountain areas: The mountain chains of the Himalayas, the Karakorum and the Hindukush, as well as the hilly land of the Himalayas foothills, appear in the north and northwest of the country. They are characterized by steep slopes, deeply incised valleys, rugged and fissured crests. Mechanical weathering due to fissuring by frost, translocation of detritus by gravity, solifluction and, in particular, on slopes facing south, high erosivity by rainfall prevent the development of soil profiles. Only shallow soils, lithic subgroups, Rankers and, if carbonaceous rocks form the bedrock, Rendzinas (Rendolls) may develop.

In areas protected from soil-erosion, soil-forming processes are considerably advanced due to favourable climatic conditions (Udic Soil Moisture Regime).

Intramountain basins and weathered bedrock plains: The Murree Basin, the Kashmir Basin and basins in parts of the Potwar Plateau developed by weathering in situ and deposition of colluvium. They are commonly associated with loess plains. There are also plains covered by loess-like fluviatile sediments, dominantly clay. Impermeable substrata and dense bedding of the soil material cause insufficient drainage.

Piedmonts form a belt of detritus between the western mountains and the Indus Plain. MIAN & SIAL (1986) differentiated 3 landforms within the Piedmonts: Bahadas, Piedmont terraces, basins and playas.

Bahadas are the alluvial fans close to mountains. They begin at the mouths of gorges and spread cone-like over the adjacent slopes along the mountain front. As the inclination of the slopes decreases, the fans unite and grade into more or less fine-textured sediments of the plains. Examples of the alluvial piedmont plains are the Damans of the Derajat Basin, which are highly dissected by intermittend streams.

Within the Piedmonts, **terraces** have been formed, partly by tectonic movements, by lowering the base of erosion, or by flowing water. The terraces are gravelly, loamy or clayey. Their surfaces are generally gashed by torrential streams. In the western arid regions, the terraces reach a height of about 60 m, their slopes range from 25 % - 55 %. In the area of Peshawar and Bannu, silty and sandy terraces, characterized by gentle slopes, exist as mesa-like elevations between deeply incised channels.

Basins and playas are the lowest parts of the piedmonts. Basins are connected with the main drainage streams at drainage outlets and their direct surroundings. (Peshawar Basin, Kohat Basin, basins in the Sulaiman and Kirthar Ranges). Due to drainage, hazard of salinization in the basins is low. **Playas** are intermountain depressions in some of the arid areas of Baluchistan. They have no external outlet. Evaporation results in the formation of salt lakes or salt crusts on top of the silty or clayey sediments.

Sandy deserts cover approximately 14.8 % of the country's total land surface. They are the Thal Desert, also known as the Sin Saga Doab between the rivers Jhelum and Indus, the Cholistan Desert south of the Sutlej and east of the Indus River, the margin of the Thar Desert east of the Indus River, and the Chagai – Kharan Desert in Baluchistan. The material forming the sand dunes of the Thal Desert derived from fluviatile deposits of the Indus River sedimented during the River's gradual migration from an easterly, older course to its present position.

The sediments of the Cholistan and Thar Deserts apparently are a combination of materials derived from the alluvium of the Indus River system, weathered rock debris of the Aravallis Mountains and marine sediments of the Rann of Kutch. The sediments of the little explored Chagai – Kharam Desert probably derived from wind-transported sands. Depending on direction and strength of the winds, longitudinal, transverse and alveolar dunes are formed. Also Barchan sand dunes occur in all desert areas. In the Thal Desert, the dunes consist entirely of fine sands up to 150 m thick.

The sandy deposits in the marginal areas of the Thar Desert commonly include layers of gravel caused by floods of the Indus River or its predecessors.

Loess plains form the sandy plains which appear along the ancient rivers. Silt-size and finer material was blown out by cyclonic winds during Late Pleistocene. The aeolian material was deposited on the existing landscape like a blanket, probably together with snow. While the loess swiftly and easily eroded from sloping surfaces it escaped gully and sheet erosion on level table land. Under Udic Soil Moisture Regime the loess-derived soils underwent decalcification, development of an argillic horizon and formation of a lime accumulation zone. In semiarid and arid areas loess-derived soils are not completely decalcified. On sloping and undulating surfaces the loess mantle was dissected by rill- and gully-erosion. The interfluves between gullies are subject to sheet erosion. There are patches of land where the width of the interfluves is reduced drastically; thus that their cultivation has become impracticable.

Fluviated loess plains developed in structural depressions where erosion products from the adjecent loess areas accumulated. The material is generally clayey. Impervious substratum resulted in poor drainage. The most extensive basins filled with fluviatile loess are found in the Peshawar Basin, and in the Hangu and Tal Valleys.

Pleistocene river terraces, locally called "bar", derived from Pleistocene deposits of the Indus River system. During later interglacial periods, fluvial loess transported from the Himalayas was sedimented on top of the terrace sediments. The tributaries of the Indus River (Jhelum, Chenab, Ravi and Sutlej) carved into these sediments, and mesa-like terraces were cut out. They are separated by steep escarpments from terraces and plains formed later on. The difference in altitude between the "bar", younger terraces and recent river plains ranges from a few centimeters to 9 meters. The characteristics of old river landscape, i.e. relict oxbows, indistinct basins and covered levees, are hardly discernible. These features, however, are of major importance for soil dynamics because they represent differences in soil moisture, salt accumulation and leaching of soluble salts.

Limited moisture and warm climatic conditions influenced the pedogenesis of the Pleistocene deposits. Weathering, brownification, leaching, lime redistribution and structure development are the soil forming processes. Despite the weak pedogenetic environment, the soils show some pronounced soil morphological features due to long periods of soil development.

Besides the Pleistocene terraces there are also **subrecent level terraces** formed by the Kabul River and Swat River in the Peshawar Basin. Gypsiferous terraces of Early Holocene age are known from the Sindh and Punjab region.

Flood plains are differentiated according to their age. Subrecent flood plains cover extensive areas from the Indian border in the Punjab to the Indus Delta near Hyderabad. They are extensively used for irrigated agriculture. Here, the following subdivisions can be applied: Level plains arise from sedimentation of silt and fine silt in slowly flowing waters. Variations in the relief of these sediments, as insignificant as they may seem, cause hazards of salinisation and water logging. Shallow basins and infilled waterways, which constitute the lowest part of this landform have silty or clayey soils and the ground remains moist from surface runoff for a longer period. The fringes of these landforms, as well as other slightly elevated areas are subject to salinisation or sodification. Infilled water ways differ from basins by their narrowness and meandering trend. Their original levees are mostly covered, although, locally, the tops of the levees were not reached by sheet floods and therefore not covered by sediments.

The recent flood plains include regularly-flooded areas and recent meander flood plains near, or adjoining, river channels. River channels and regularly flooded areas are affected by continuous erosion and sedimentation and therefore are unstable. Recent meander flood plains form narrow belts along rivers. Lying above the seasonal flood level, they have attained a certain degree of stability. Nevertheless, soil formation has not begun in these sediments.

In the **Indus Delta**, land is formed when the rising tide from the Arabian Sea blocks the river discharge, with consequent flooding by sediment-laden spillwater and inundation of the surroundings. Thus the estuary plain contains a variety of landforms, i. e. spillflats, basins, spillheads, meander-barriers and levees. Well-sorted silty material forms the almost level spill flats. The basins are filled with clay. Levees and meander-bars consist mainly of silt, but partly of fine sand. The coastal belt is subject to regular inundation. As a result of the tide, depressed areas are continuously flooded but higher sites are in general flooded fortnightly.

11.13 Lithology and soil formation

In the northern and western high mountains, bedrock is significant for soil formation, but locally only because soil forming processes in situ are hardly possible. Potentially fertile soils, rich in plant nutrients, exist in the highlands, but only in small intermountain valleys and basins and on piedmonts. In areas protected from erosion, soil development may be advanced very far due to favourable climatic conditions. Fine-grained clayey soils having a high erodibility may derive from argillaceous rocks, e.g. from the Murree Formation. Nutrient content and adsorption capacity of these soils depend on the clay mineralogy, the climatic conditions prevailing during their formation, and the foregoing

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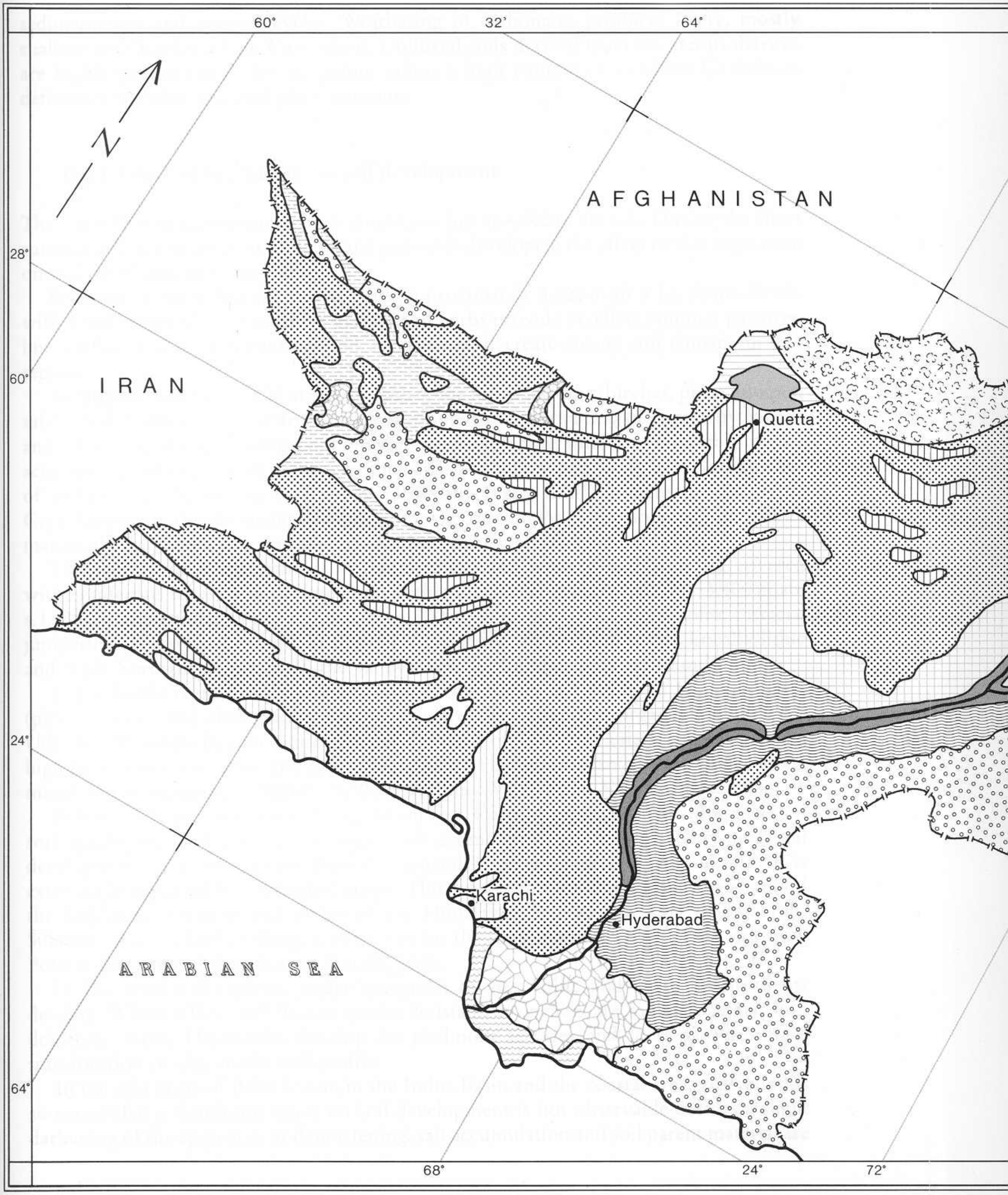
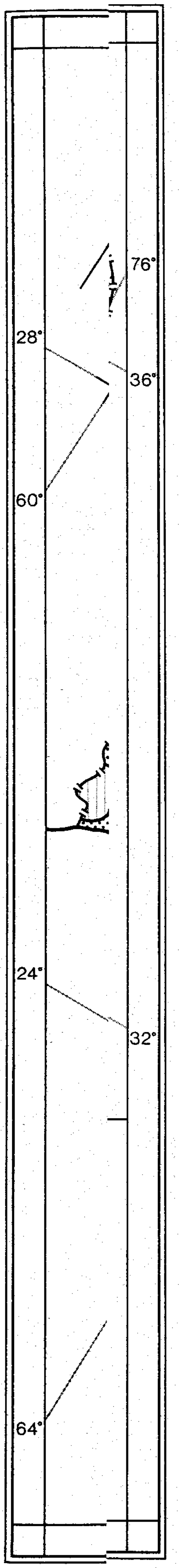


Fig. 11.1. Generalized Soils Map of Pakistan Scale 1 : 500 000. Distribution of principal Great Groups (after MUSHTAQ & AMIN (



LEGEND

NORTHERN MOUNTAIN AREA

☐ Perennial snow

▨ Association of Mollisols and Inceptisols under cryic, xeric or ustic SMR:
MOUNTAINS: Haploxerolls, Cryoborolls and Haplustolls
VALLEYS: Xerochrepts and Ustochrepts with some Ustifluvents

▨ Association of Entisols and Inceptisols under cryic and xeric SMR:
Cryorthents, Xerorthents, Xerofluvents and Xerochrepts

▨ Association of Mollisols, Alfisols and Inceptisols under ustic SMR:
Hapludolls, Hapludalfs and Eutrochrepts

▨ Assocoation of Mollisols, Inceptisols and Entisols under ustic SMR:
Haplustolls, Ustochrepts and Ustorthents

▨ Association of Alfisols, Inceptisols and Entisols under ustic SMR:
Haplustalfs, Ustochrepts and Ustorthents

▤ Association of Limestone derived Entisols and Inceptisols under ustic SMR:
Ustorthents and Ustochrepts
(Khanpur-, Buner- and Khattak-Hills)

WESTERN MOUNTAIN AREA

▨ Xerorthents and Xerochrepts

▤ Ustorthents and Ustochrepts

▨ VALLEYS: Camborthids and Calciorthids with some Torriorthents
MOUNTAINS: very patchy cover of heterogenous soil materials

▥ Camborthids and Calciorthids with some Torriorthents

▨ Camborthids and Torriorthents with some Torrifluvents

▦ Camborthids and Torripsamments

PUNJAB (semihumid zone)

▨ Ustochrepts

▨ Ustochrepts and Haplustalfs
(Old Terraces, "Bar" Uplands)

PUNJAB (semiarid & arid zone)

▤ Association of Haplargids, Natrargids, Camborthids and Calciorthids
(Old Terraces, "Bar" Uplands)

☐ Camborthids, Torriorthents and some Torrifluvents
(Younger Terraces, "Doabs")

INDUS PLAIN

▦ Camborthids with some Torrerts and Torriorthents
(Bahadas west of Indus river)

▤ Camborthids, Salorthids and Torripsamments
(Indus subrecent flood plain)

▨ Torrifluvents with some Torripsamments and Camborthids
(Indus recent flood plain)

▨ Salorthids and Camborthids with some Torrifluvents
(Indus estuarine plain)

▨ Salorthids and Haplaquents
(Tidal Flats)

DESERT AREAS

▨ Torripsamments.

▥ Camporthids, some Torripsamments and Salorthids

BALUCHISTAN PLAIN

▤ Torriorthents, Calciorthids and Gypsiorthids

▨ Haplaquents and Salorthids (Playas)

Fig. 11.1.

sedimentation and erosion cycles. Weathering of carbonates produces stony, mostly shallow soils having a high Ca-content. Colluvial soils derived from calcareous detritus are highly productive under irrigation, unless a high content of available Ca induces deficiency in other essential plant nutrients.

11.14 Effect of vegetation on soil development

The snow line in the region of high mountains lies at 4,000 m ab. s. l.. During the short summer a scarce vegetation of herbs and grasses is developed; the effect of this vegetation on soil development is very low.

Between the snow line and the tree line (approximately 3,800 m ab. s. l.), alpine shrubs with a wide variability of nutritive grasses and herbs provide excellent summer pastures, but solifluction, frost shattering, and surface runoff create strong soil damage in this region.

At altitude 3,400 m - 3,800 m ab. s. l., subalpine forest appears (birches, pines, juniper, salix, rhododendron). These trees may contribute to the formation of humus by foliage and litter, and, during summer, soil moisture and soil temperature are favourable for the activities of soil organisms. However, the soils are shallow and stony as a consequence of soil erosion. According to BAIG & QUAMAR (1986), lithic Cryochrepts and typic Cryochrepts are the dominant soil sub-groups in that region. Deep soils rich in organic matter, the Mollisols, are scattered at locations protected from soil erosion.

The regions of winter rainfall in the northern and western highlands are covered with coniferous forest (pinus, juniperus) within altitudes between 1,800 m - 3,400 m ab. s. l. Below the conifer zone, at 1,800 m - 1,200 m, is an evergreen forest (olea, pistacia, juniperus). The steeper mountain slopes are generally without soil cover. Locally lithic and typic Xerorthents occur. In the valleys, xerollic Camborthids are found.

In the humic region, moist conifer forest predominates at 1,400 m - 3,100 m altitudes (pinus-, picea-, and abiesspecies, *Cedrus deodare*). The abundant organic matter under Udic Soil Moisture Regime causes the development of soils with a dark epipedon, and a high base saturation (lithic and typic Hapludolls). Hapludolls also develop under moist mixed forests occuring at 900 m - 1,500 m altitude (Murree and Kahuta highlands).

Below 1,200 m, variations of vegetation are scarcely expressed by differences of soil development. Climatic, lithologic and geomorphologic features determine soil development more intensively than the generally scarce natural vegetation, which is extensively replaced by cultivated crops. This holds true for the semi-arid regions of the highlands (foothills and slopes of the Himalayas, Salt Range, Kala Chitta Hills, Sulaiman Range, Kirthar Range), as well as for the semi-humid regions of the northern Potwar Plateau and the adjacent Siwalik Hills.

In the semi-arid regions, under evergreen bushes, lithic and typic Torriorthents develop. Where Olea- and Acacia species resistant to dryness are found together with decideous trees, Haplustalfs develop on piedmont terraces and loess as a result of translocation of clay in the soil profile.

In the arid areas of Baluchistan, in the Indus Basin and the coastal area, vegetation is so scarce that a significant effect on soil development is not observable besides a slight darkening of the epipedon. Soil moistening, salt accumulation and soil parent material are the dominant factors of soil dynamics. The mangrove forest in the coastal area southeast of Karachi seems to be an exemption, because the root system of the mangroves supports the sedimentation of marine deposits. Recent deposition and high salt contents of the marine sediments is, however, of greater importance for soil development than the effect of mangrove vegetation.

11.2 Classification and distribution of soils

The soil classification used by the Soil Survey of Pakistan is based on the US Soil Taxonomy (US Soil Survey Staff 1975). According to MUSHTAG & UL-AMIN (1986), 6 of the 10 soil orders provided for in this taxonomy are developed in Pakistan. The distribution of soil associations is shown in Fig. 11.1 (Soil Map, fold-out). Orders and sub-orders, arranged according to the area covered, are described in the following. Great Groups observed are listed in tables 11.4 through 11.10.

The taxonomic units of the US Soil Taxonomy are not identical with those of older classification systems, e.g. the Great Groups and sub-groups of the legend of the Soil Map of the World 1 : 5,000,000 (FAO/UNESCO 1974). On Table 11.3, a correlation is shown between the nomenclature used for the Soil Map of the World 1 : 5,000,000, Sheet III, 2 (FAO/UNESCO 1977) and the one applied here.

Table 11.3. Comparison between the nomenclature of the FAO-UNESCO Soil Map of the World 1 : 5,000,000 and the USDA soil taxonomy used for the territory of Pakistan (after FAO–UNESCO Soil Map of the world Vol. VII South Asia (1977) and after MUSTAQ & AMIN (1986), pp. 31–44).

1 Great Group	2 sub-group or Soil Association	3 characteristics of Great Group or sub-group	4 area mio ha	5 distribution	6 approximate equivalents USDA Soil Taxonomy (Soil Survey Staff 1975)
Lithosols $I - B - U$	cambisols (B) rankers (U)	solum < 10 cm	2.82	northern mountains	lithic sub-groups of cryoborolls, haploxeroll, haplustolls
Lithosols $I - X_c$	xerosols calcaric	solum < 10 cm winterrain	3.40	mountains west of Potwar-Plateau	lithic sub-groups of xerorthents & xerochrepts
Lithosols $I - R_c - Y_k$	calcaric regosols, calcaric yermosols	solum < 10 cm above unconsolidated debris of calcaric rock	27.5	piedmonts & mountainous area west of Indus River	lithic ustorthents, lithic ustochrepts, camborthids, calciorthids

Table 11.3. Continued.

1 Great Group	2 sub-group or Soil Association	3 characteristics of Great Group or sub-group	4 area mio ha	5 distribution	6 approximate equivalents USDA Soil Taxonomy (Soil Survey Staff 1975)
Cambisols B_e	eutric C. lithic C.	cambic hor. no lime, base satur. > 50 %	2.46	inter-mountainous basins & valleys in northern mountains	hapludolls, eutrochrepts
Aerosols X_h	haplic X.	weak ochric epipedon cambic horizon, no argillic, calcic, gypsic hor.	1.59	Peshawar-, Bannu Basin, Kunar Valley	ustorthents, ustochrepts
Aerosols X_k	calcic X.	weak ochric epipedon calcic horizon within 125 cm	0.84	Punjab	ustochrepts, aridic ustochrepts
Regosols R_c	calcaric R.	ochric epipedon above unconsolidated coarse sediments, within 20 – 50 cm calcareous	1.09	Potwar Plateau	lithic ustochrepts, lithic hapludalfs
Yermosols Y_h	haplic Y.	weak ochric epipedon, aridic moisture regime	13.16	doabs in Punjab, Indus flood plain in Sindh	haplargids, camborthids, calciorthids torriorthents, some torrifluvents
Arenosols Q_c	cambic A.	sandy texture throughout, ochric epipedon, indications of clay-or ironhydroxydformation in situ	11.82	Thal-, Cholistan-, Kharam-Chagai-Desert, fringes of Thar-Desert	torripsamments

Table 11.3. Continued.

1 Great Group	2 sub-group or Soil Association	3 characteristics of Great Group or sub-group	4 area mio ha	5 distribution	6 approximate equivalents USDA Soil Taxonomy (Soil Survey Staff 1975)
Fluvisols J_c	calcic F.	alluvial soils of river plains within 20 – 50 cm calcareous	3.89	flood plain of Indus River and its tributaries	torrifluvents
Solonchaks Z_g	gleyic S.	high salinity within 50 cm hydromorphic properties	1.06	Indus Delta, Haman el Mashkel playas	aquollic salorthids, typic salorthids
Solonchaks Z_o	orthic S.	high salinity ochric epipedon, no other diagnostic horizons	0.14	Mouth of Swat River	typic salorthids

11.21 Aridisols

(western mountains, semiarid and arid zone of Punjab, Indus Plain, Baluchistan plains) cover an area of 18.8 mio ha; they represent the most extensive soil order. They include mineral soils, which contain plant available moisture less than 90 days/year. The Aridic (torric) Soil Moisture Regime (SMR) governs most of the region except the mountainous areas bordering Afghanistan (Waziristan), Gilgit Agency in the north, and the Himalaya foothills, the Potwar Plateau, and the Peshawar Basin.

11.211 Orthids

(western mountains, semiarid and arid zone of Punjab, Recent and sub-Recent flood plain of Indus) make up an widespread sub-order of Aridisols. They are distinguished from other Aridisols by their ochric epipedon, i.e., a poorly developed, pale, shallow topsoil, low in organic matter. Within 100 cm below surface (b.s.) lies the upper boundary of a cambic, calcic, petrocalcic, gypsic or petrogypsic diagnostic subsoil horizon. A salic horizon may begin at 75 cm b.s.

Orthids are shown on Fig. 11.2 (fluventic Camborthid) and Fig. 11.3 (typic Salorthid).

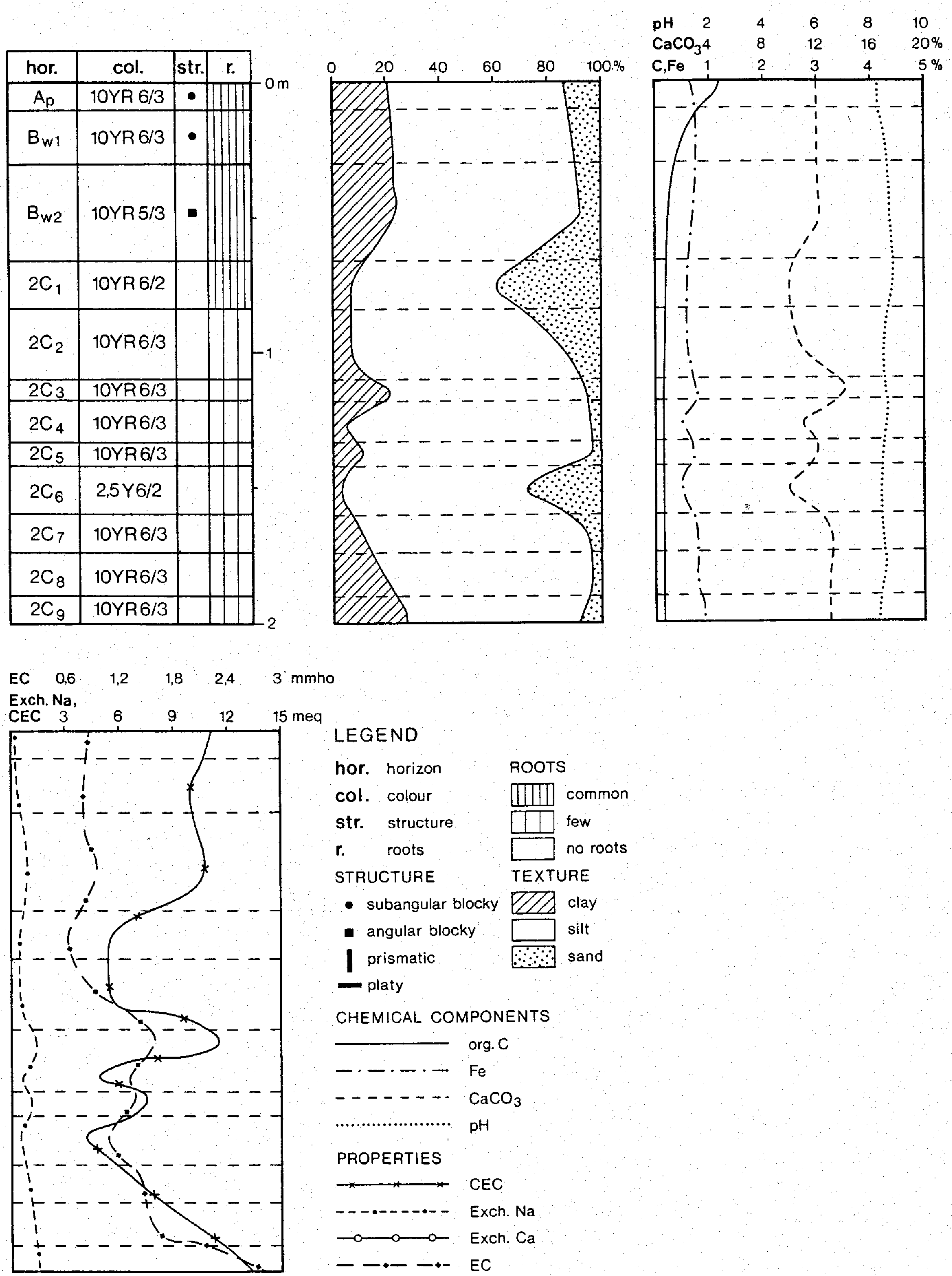


Fig. 11.2. Fluventic Camborthid, Sultanapur, 25° 24' N; 68° 25' E. Flood plain of Indus River near Hyderabad (after AMIN (1986) pp. 66–72).

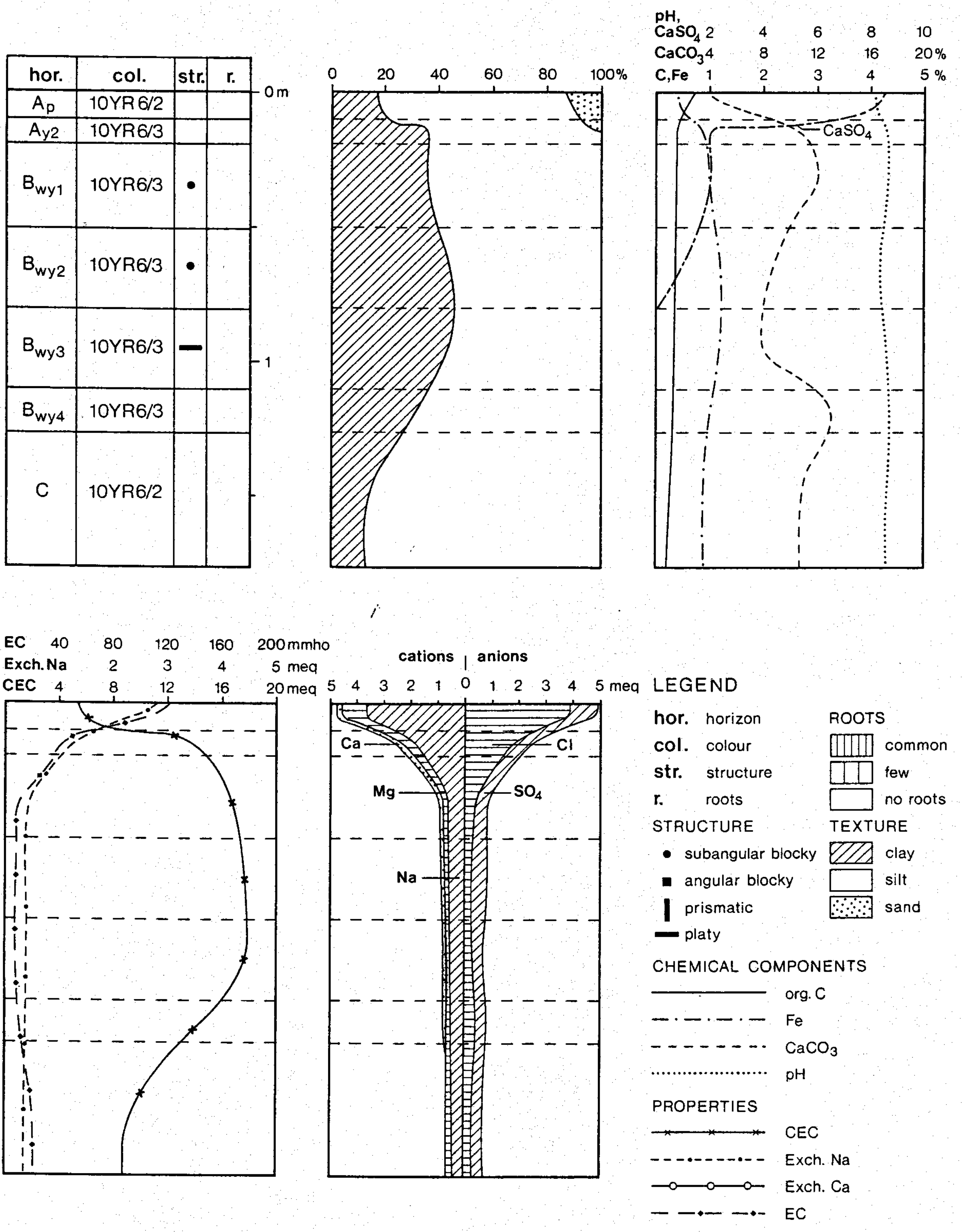


Fig. 11.3. Typic Salorthid, Pitafi, 25° 23' N; 68° 24' E. Terrace in Indus Flood Plain near Hyderabad (after AMIN (1986) pp. 80–85).

Table 11.4. Sub-order Orthids: Great groups, diagnostic horizons, properties and associations (after MUSTAQ & AMIN (1986) p. 36).

Great Group	diagnostic horizons	properties	associations	selected sub-groups shown on figs.
Camborthid	cambic hor. B_w	Fe-oxidat., formation of clay in situ	western mountains, semiarid and arid zone of Punjab, Indus Plain, Baluchistan Plain, coastal area	fluventic Camborthid Fig. 11.2
Calciorthid	calcic or petrocalcic horiz.	$CaCO_3$ within 100 cm b.s.	western mountains, semiarid and arid zone of Punjab Baluchistan Plain	–
Gypsiorthid	gypsic or petrogypsic horiz.	$CaSO_4$ soft or rock within 100 cm b.s.	Baluchistan Plain	–
Salorthid	salic horizon	2 % salt within 75 cm b.s.	Indus subrecent floodplain, Indus estuarine Tidal flats	typic Salorthid Fig. 11.3

11.212 Argids

(semiarid and arid zone of the Punjab) are mineral soils of the Aridic SMR which, below the epipedon, present a diagnostic horizon of illuviated clay particles (argillic horizon). In areas of slender water percolation, a long period of soil development and permeability of the subsoil are the prerequisites for the translocation of clay particles. Both prerequisites exist on Pleistocene terraces, the “Bars” of the eastern Punjab. Argids are shown on Fig. 11.4, Ustalfic Haplargid, and on Fig. 11.5, Typic Natrargid.

Table 11.5. Sub-order Argids: Great groups, diagnostic horizons, properties and associations (after MUSTAQ & AMIN (1986) pp. 34–35).

Great Group	diagnostic horizon	properties	associations	selected sub-groups shown on figs.
Haplargid	argillic horizon	illuviated clay	semiarid and arid zone of the Punjab, Pleistocene terraces (“bars”)	ustalfic Haplargid Fig. 11.4
Natrargid	natric horizon	exch. Na > 15 % CEC	semiarid and arid zone of Punjab, Pleistocene terraces	typic Natrargid Fig. 11.5

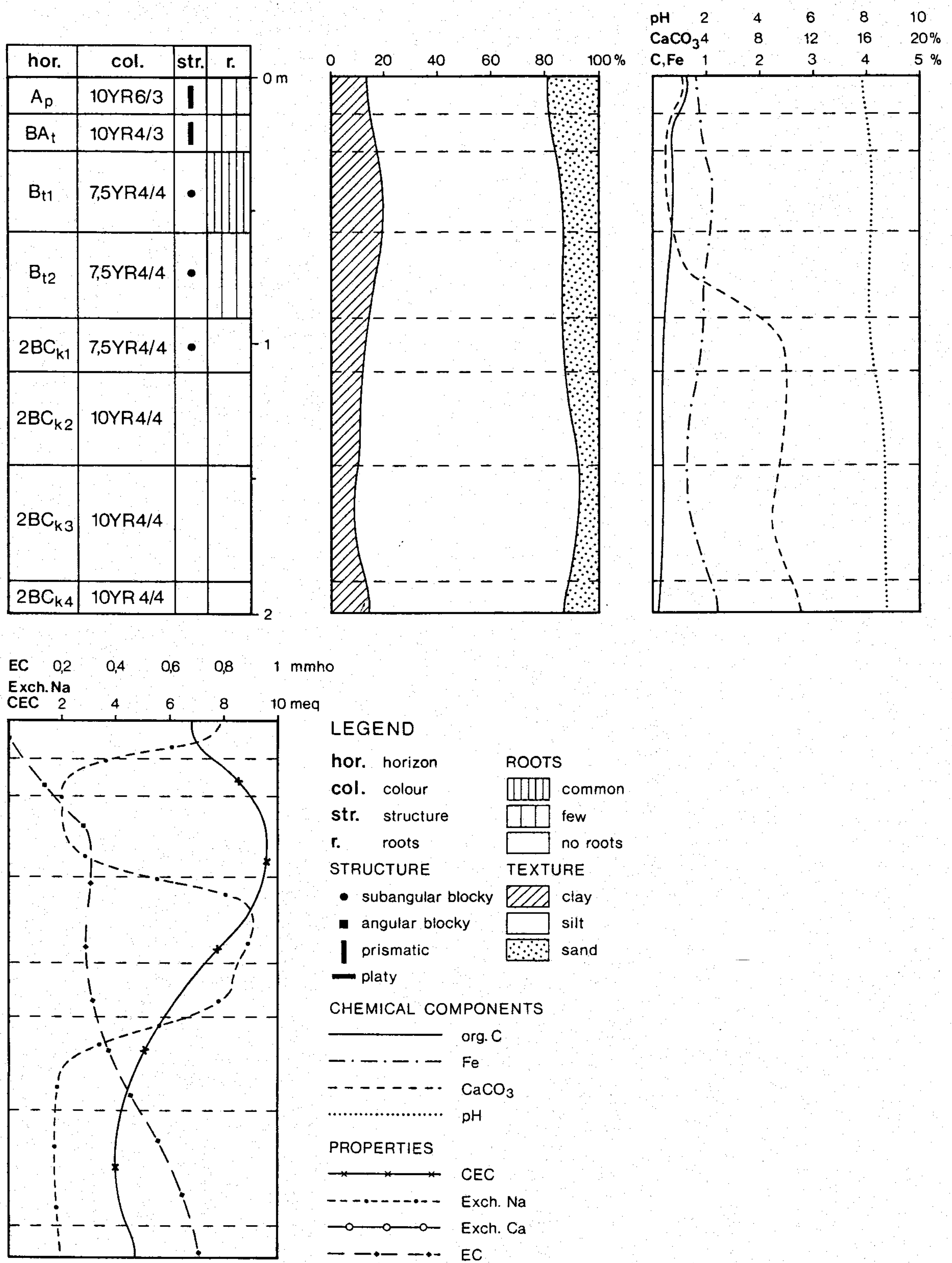


Fig. 11.4. Ustalfic Haplargid, Lyallpur, 31° 20' N; 74° 09' E. Terrace 3 Indus River Plain SW. Lahore (after AMIN (1986) pp. 93–101).

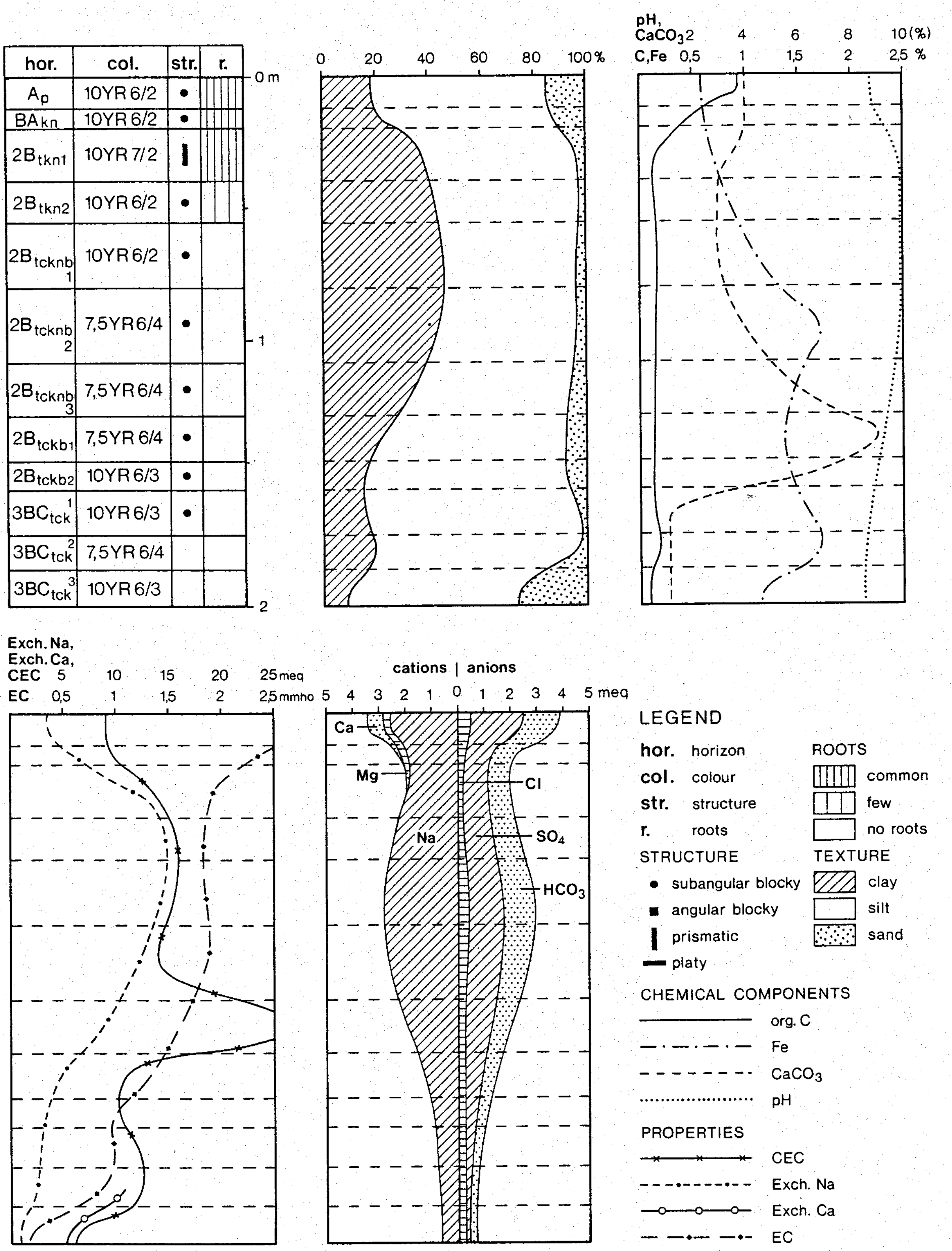


Fig. 11.5. Typic Natrargid, Satghara, 31° 43' N; 74° 09' E. Alluvial of Ravi River N of Lahore (after AMIN (1986) pp. 183–192).

11.22 Entisols

are the soils in the earliest stage of development. There may be an ochric, anthropic or histic epipedon, but no diagnostic horizons are developed. Entisols comprise an area of 9.5 mio ha. Almost all soil association shown on Fig. 11.1 (soil map) include an Entisol.

11.221 Aquents

(Tidal flats), are Entisols saturated with water continuously below 25 cm b.s., or temporarily below 50 cm b.s. continuously saturated. The matrix shows a blue hue, which changes into brownish when exposed to air (G_r-horizon). If the saturation is temporary, the soil is mottled (G_o-horizon) as a result of oxidation. In Pakistan, Aquents are represented by the Great Group **Haplaquents**, associated with Salorthids in the tidal flats of the coastal region, and in the playas of desert areas in Baluchistan.

11.222 Fluvents

comprise the Entisols of the river flood plains. Due to deposition of recent sediments in frequent intervals, no diagnostic horizons are developed; within the soil profile the content of organic carbon is irregular.

Table 11.6. Sub-order Fluvents: Great groups, diagnostic horizons, properties and associations (after Mustaq & Amin (1986) p. 38).

Great Group	diagnostic horizon	properties	association	selected sub-groups shown on figs.
Torrifluvent		aridic SMR	western mountains, semiarid and arid zone of Punjab	–
Ustifluvent		ustic SMR	–	–
Xerifluvent		xeric SMR	valleys in the mountain region	–

11.223 Orthents

(northern mountain area, Khantur-, Buner-, Khattak hills; western mountains, terraces in Punjab, Baluchistan plains) comprise the Entisols of mountainous regions, which are subject to severe soil erosion. Due to the steady removal of existing or developing soil, unweathered bedrock is often exposed. Within 100 cm b.s., Orthents may contain more than 35 % stones by volume. A lithic or paralithic contact may appear at shallow depth. The content of organic carbon decreases regularly from the epipedon to the subsoil. There are no signs of waterlogging. The Great Groups in this sub-order are defined according to soil temperature or soil moisture regimes. Fig. 11.6 represents a typic Ustothent on a dissected loess plain west of Rawalpindi.

Table 11.7. Sub-order Orthents: Great groups, diagnostic horizons, properties and associations (after MUSTAQ & AMIN (1986) p. 38).

Great Group	diagnostic horizon	properties	association	selected sub-groups shown on figs.
Cryorthent	none	soil temp. 0 – 8 °C	–	–
Torri-orthent	none	aridic SMR	–	–
Xerorthent	none	winter-rainfall	–	–
Ustorthent	none	summer-rainfall	–	typic Ustorthent Fig. 11.6

11.224 Psamments

(sandy desert, western mountains, Indus subrecent flood plains, Indus recent flood plains) include the Entisols having sandy texture at least to 100 cm b.s., and contain less than 35 % stones by volume.

Table 11.8. Sub-order Psamments: Great groups, diagnostic horizons, properties and associations (after MUSTAQ & AMIN (1986) p. 38).

Great Group	diagnostic horizon	properties	association	selected sub-groups shown on figs.
Torri-psamment	deep sand-dunes	aridic SMR	–	–
Usti-psamment	deep sandy soils	ustic SMR summerrain	–	–

11.23 Inceptisols

(Northern and western mountains, semi-humid zone of Punjab). The order Inceptisols comprises soils, which, below the epipedon, developed a cambic horizon (B_v, B_w). This

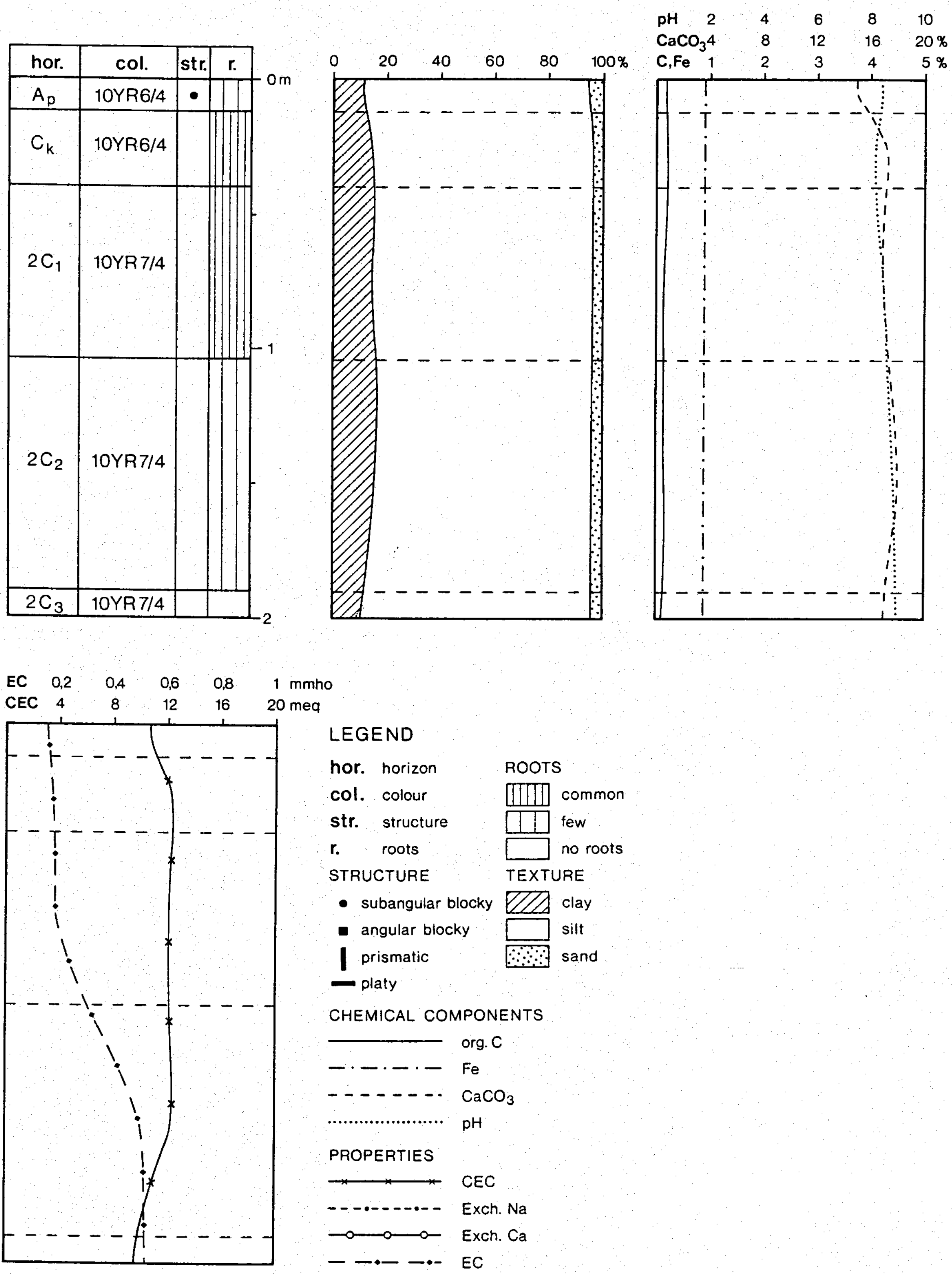


Fig. 11.6. Typic Ustorthent, Rajar, 33° 38' N; 72° 56' E. Dissected Loessplain W of Rawalpindi (after AMIN (1986) pp. 201–207).

is a diagnostic horizon altered by weathering in situ, either by change of color due to oxidation of Fe (brownification), or by the formation of new, secondary clay minerals (loamification). The cambic horizon may have lost its bases by leaching, but still contains abundant weatherable primary minerals. They cover an area of 2.9 mio ha.

11.231 Aquepts

include Inceptisols, which are saturated with water close to the surface, at least periodically. They are represented by **Haplaquepts** in the eastern Punjab. Their areal extension is very limited (not shown on Soil Map, Fig. 11.1).

11.232 Ochrepts

(Northern and western mountains, semi-humid zone of Punjab) have a shallow, pale colored epipedon low in organic carbon. Ochrepts are shown on Fig. 11.7, Typic Ustochrepts, and on Fig. 11.8, Udic Ustochrept.

Table 11.9. Sub-order Ochrepts: Great groups, diagnostic horizons, properties and associations (after MUSTAQ & AMIN (1986) pp. 39–41).

Great Group	diagnostic horizon	properties	association	selected sub-groups shown on figs.
Eutrochrepts		abundant plant nutrients	northern mountains	lithic Eutrochrepts
Distrochrepts		base saturation < 50 %		lithic Distrochrepts
Ustochrepts			northern mountains western mountains	typic Ustochrept Fig. 11.7 udic Ustochrept Fig. 11.8
Xerochrepts		high base saturation xeric SMR	–	–

11.24 Alfisols

(Northern mountains, semi-humid zone of Punjab). Alfisols are mineral soils with an illuvial horizon enriched with translocated clay. The clay may be precipitated as cutans on the surface of structural aggregates, on walls of pores, root channels or animal passages (argillic horizon, Bt horizon). Instead of an argillic horizon there may appear

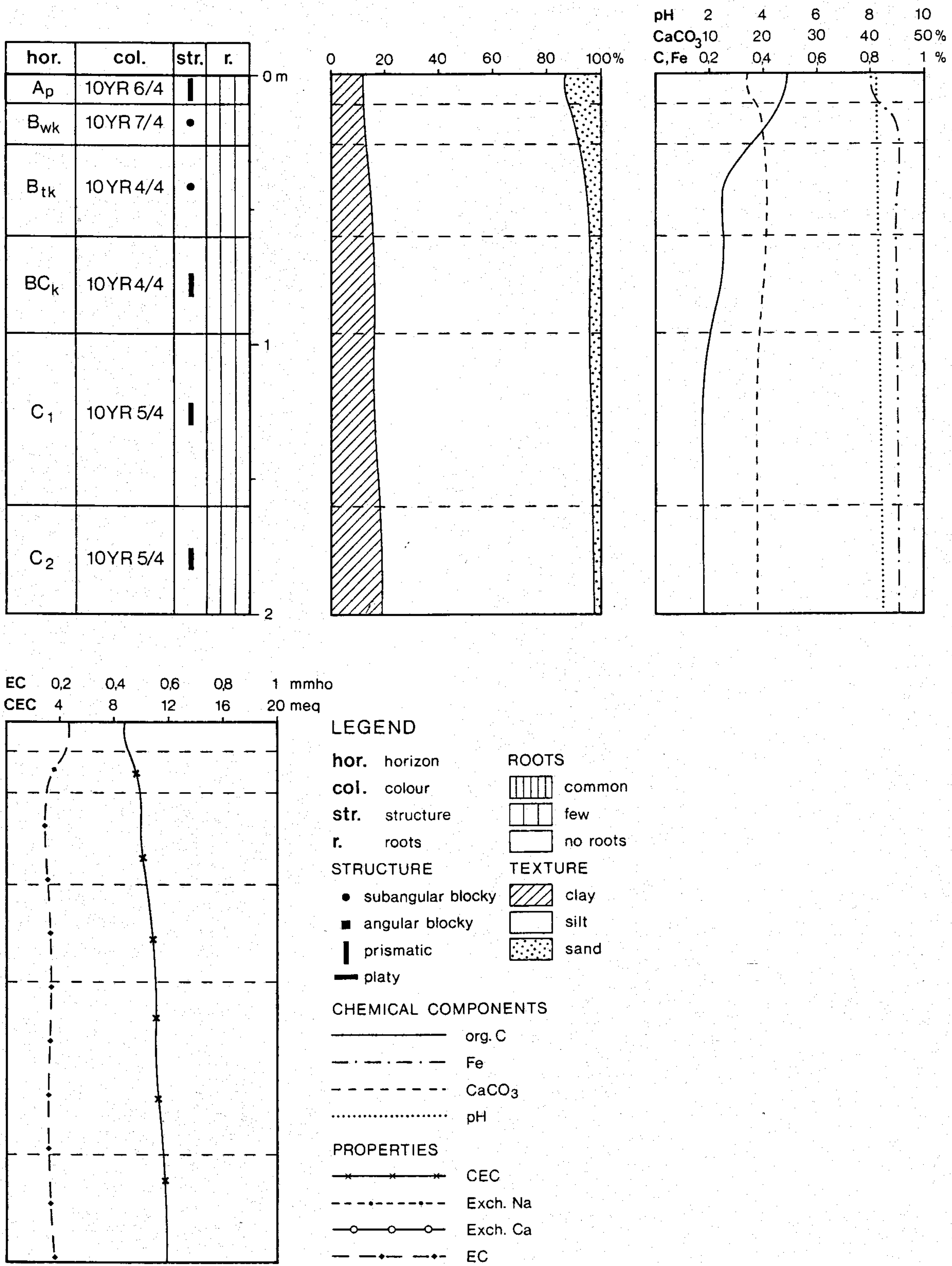


Fig. 11.7. Typic Ustochrept, Missa, 31° 36' N; 72° 49' E. On Loessplain of Potwar Plateau (after AMIN (1986) pp. 226–234).

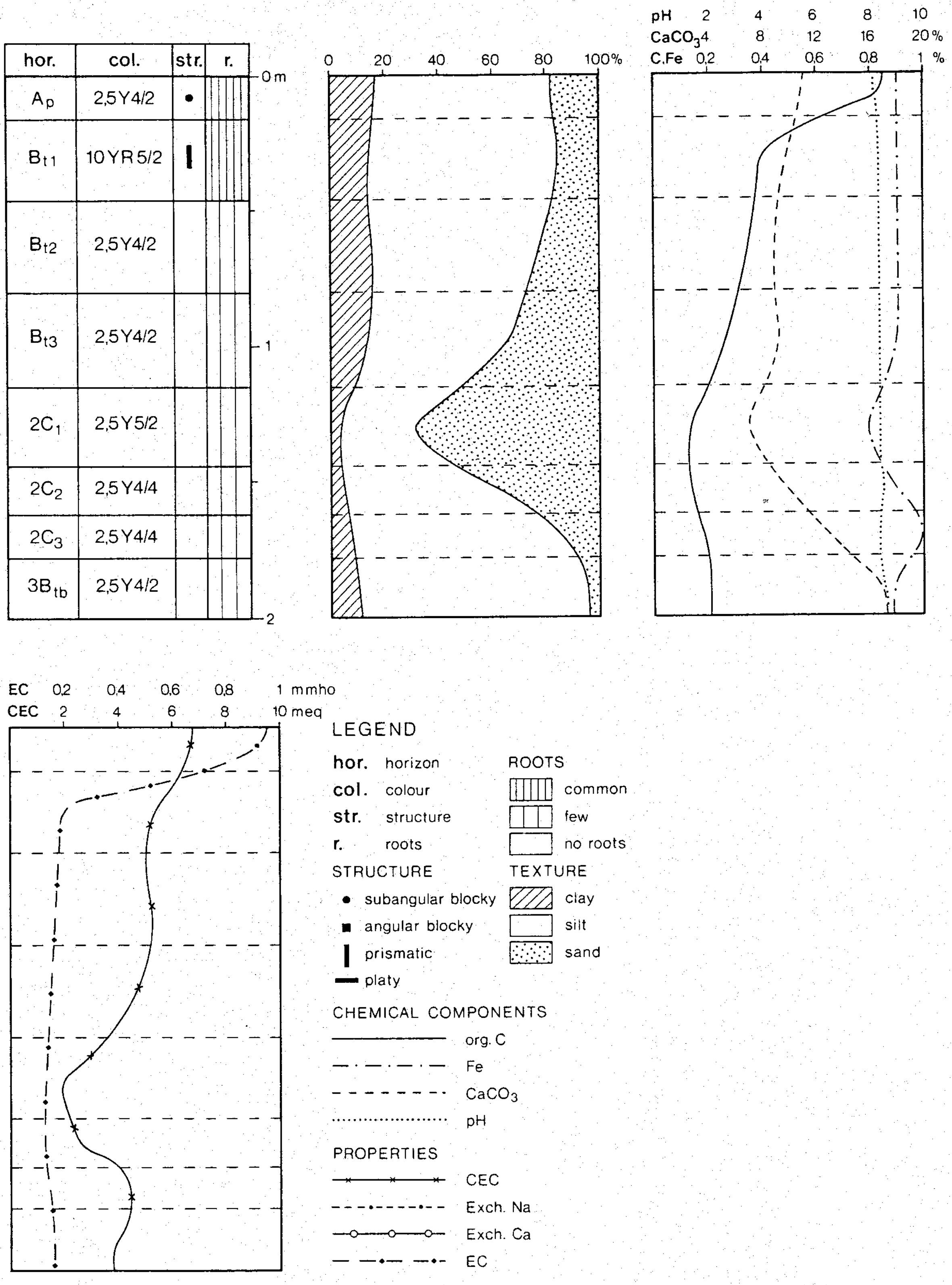


Fig. 11.8. Udic Ustochrept, Warzak, 34° 06' N; 71° 35' E. Alluvial deposit of Kabul River N of Peshawar (after AMIN (1986) pp. 243–250).

a natric horizon containing more than 15 % exchangeable Na. Connencted with the Na-accumulation is the dispersion of clay and the resulting clay translocation. Alfisols comprise an area of 0.8 mio ha.

Leaching of exchangeable bases, dispersion and mobilisation of clay in the eluvial horizon and a freely draining subsoil are prerequisites for the formation of Alfisols, soils of this order exist only in areas having comparatively high precipitation.

11.241 Udalfs

are represented by the Great Group of **Hapludalfs** in the temperate climatic zone of the Himalayas. They are also observed in the valleys north of the Potwar Plateau and in the Peshawar Basin (Khanpur Hills, Hazara Highlands, Buner Hills), in particular on loess blankets.

11.242 Ustalfs

are Alfisols with an Ustic SMR mostly showing a massive ochric epipedon. They may have developed a calcic horizon at about 50 cm below the base of the argillic horizon. The calcic horizon is marked by finely-distributed lime, by soft powdry lime at the surface of structural aggregates, or by spheroid concretions. Because rainfall is concentrated during hot seasons, moisture movement through the entire soil profile occurs only during exceptionally wet years. A calcic horizon below the argillic horizon can only develop when calcareous bedrock exists, or calcareous dust is sedimented on the soil surface. Ustalfs are shown on Fig. 11.9, Udic Haplustalf and Fig. 11.10, typic Natrustalf.

Table 11.10. Sub-order Ustalfs: Great groups, diagnostic horizons, properties and associations (after MUSTAQ & AMIN (1986) p. 33).

Great Group	diagnostic horizon	properties	association	selected sub-groups shown on figs.
Haplustalf	argillic horizon	high base saturation	–	udic Haplustalf Fig. 11.9
Natrustalf	natric horizon	exch. Na > 15 % CEC columnar structure	–	typic Natrustalf Fig. 11.10

11.25 Mollisols

Mollisols are indicated by a dark colored (at least 10 cm thick) epipedon, rich in organic carbon, and saturated with bases (mollic epipedon). A cambic, argillic, natric or calcic

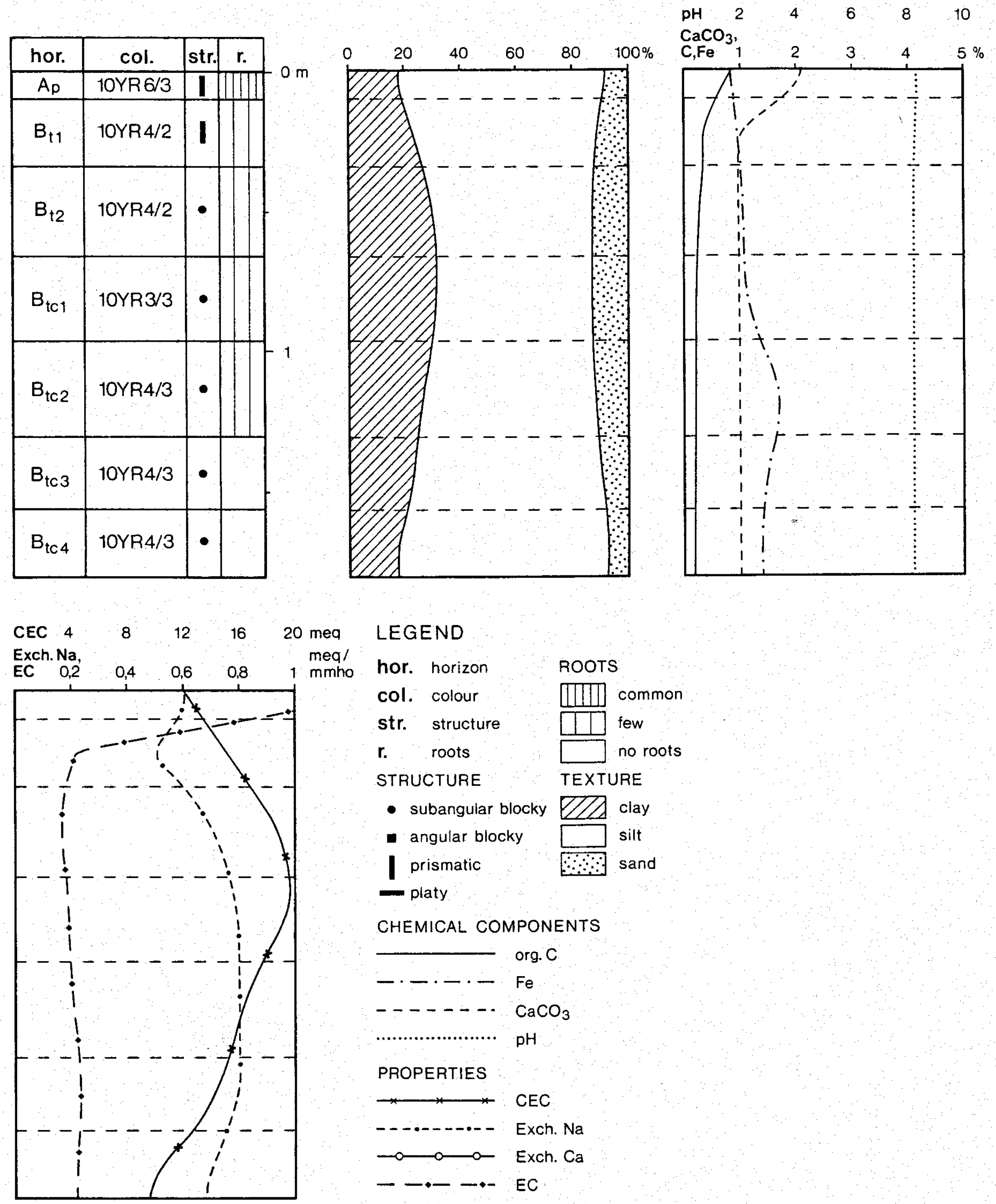


Fig. 11.9. Udic Haplustalf, Gujranwala, 32° 11' N; 74° 09' E. Terrace 3 of Indus River Plain NW of Gujranwala (after AMIN (1986) pp. 151–158).

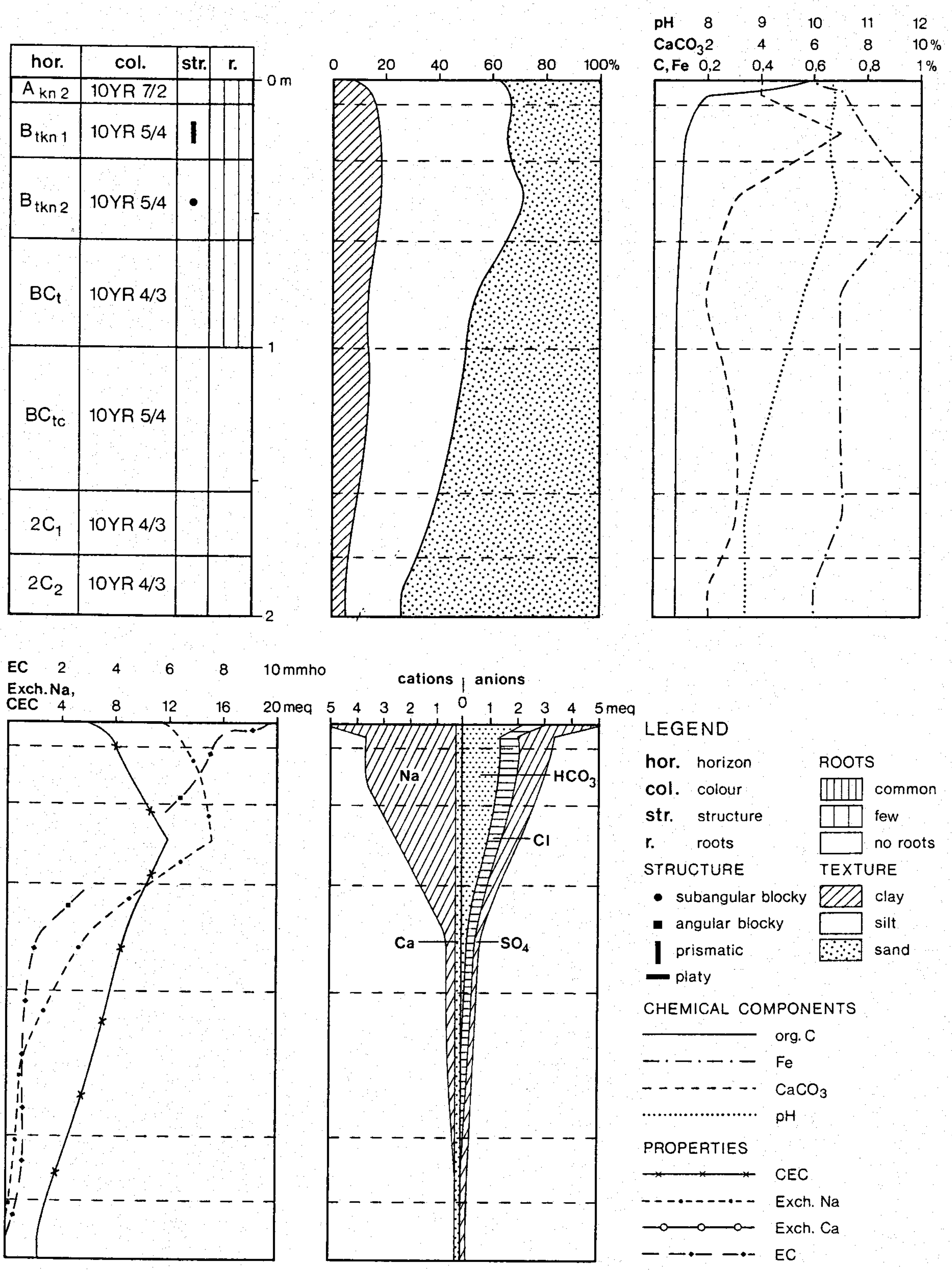


Fig. 11.10. Typic Natrustalf, Eminabad, 32° 01' N; 72° 12' E. Terrace 3 of Indus River Plain, Playalike (after AMIN (1986) pp. 169–174).

diagnostic subsoil horizon may follow the epipedon. Partly, epipedon and subsoil are intercalated by a bleached albic horizon. The exchange capacity of the pedon is saturated by bases (more than 50 %) to a depth of 180 cm b.s. The epipedon contains at least 0.6 % organic carbon. If finely distributed lime is present, 2.5 % organic carbon is required. If the mollic epipedon is immediately followed by a lithic contact (Rendolls), its thickness sould be 10 cm or more. It should be at least 25 cm thick, if the base of the diagnostic subsoil horizon or the upper limit of a Ca-accumulation zone is 75 cm b.s. To distinguish a mollic epipedon from an anthropic epipedon, its P_2O_5-content should not surpass 250 ppm P.

Necessary for the development of Mollisols is the production of abundant organic matter, a soil temperature high enough to induce the decomposition of the litter but not too high to result in a fast, complete decomposition. Therefore the formation of Mollisols is restricted to the mountainuous regions having an exuberant vegetation and moderate soil temperature. The Mollisols only cover 0.75 mio ha.

11.251 Borolls

having a mean annual soil temperature of $< 8\,^{\circ}C$ are represented by Cryoborolls in the northern mountain region in association with Haplustolls, Haploxerolls and Ustochrepts.

11.252 Udolls

are Mollisols having an Udic SMR and mean annual soil temperature of $\geq 8\,^{\circ}C$ characterized by the absence of an albic horizon with spots indicating wetness. There is no calcic horizon containing > 40 % $CaCO_3$ at 40 cm below the base of the epipedon. Above 150 cm b.s., there is no accumulation of soft powdery lime. Udolls are represented as Hapludolls in association with Hapludalfs and Eutrochrepts in the foothills of the Himalayas (Fig. 11.11, Typic Hapludoll)

11.253 Ustolls

are the Mollisols of Ustic SMR. In soils developed from basic rocks there may be a calcic horizon consisting of fine dispersed soft lime concretions or spheroid lime nodules. Ustolls are represented by Haplustolls, which occur in association with Ustochrepts and Ustorthents in the Mohmand Hills and the Khyber Pass region. In the northern mountains they are associated with Cryoborolls and Haploxerolls.

11.254 Xerolls

are the Mollisols developed in the high mountain areas and represented by Haploxerolls in association with Cryoborolls and Haplustolls. The epipedon of the Haploxerolls

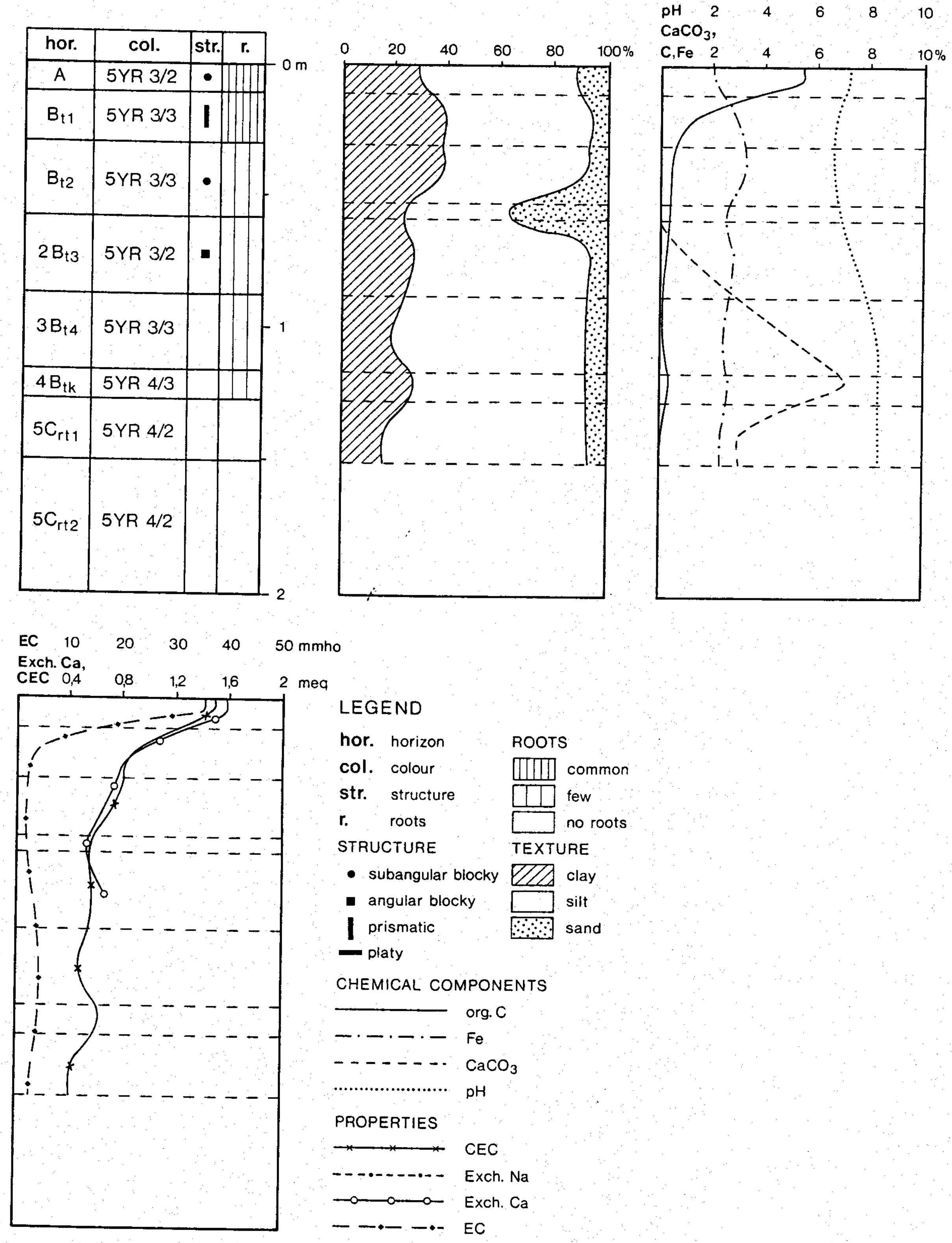


Fig. 11.11. Typic Hapludoll, Murree, 35° 56’ N; 73° 26’ E. developed in situ under mixed forest from calcareous sandstone interbedded by shale and slate (after AMIN (1986) pp. 206–216).

is locally free from carbonates. The cambic horizon below the epipedon is weakly pronounced, the bedrock merely changed.

11.26 Vertisols

Vertisols are the mineral soils which contain more than 30 % clay, mainly consisting of shrinking and swelling clay minerals. During dry periods, deep and wide shrinkage cracks are formed which close after rewetting in the rainy season. Granular surface material falls into cracks (pedoturbation). After rewetting it swells and causes the formation of "Gilgai surface" (i.e., more or less circular mounds, caused by an expanding volume of soil in middle or lower horizons). Further characteristics are slikensides and edgelike structural aggregates. Vertisols cover an area of 0.7 mio ha.

11.261 Torrerts

are the vertisols of the Aridic (torric) SMR. They are represented in association with Camborthids and Torriorthents on the bahadas west of the Indus River, and scattered on river terraces and alluvial sediments in depressions. Playas, the undrained depression in arid regions, are predominant locations for the development of Torrerts.

11.262 Usterts

the Vertisols of the Ustic SMR, are represented by the Great Group of **Chromusterts.** In contrast to the Pellusterts they have a dark-colored topsoil throughout the uppermost 30 cm. All Vertisols occur in association with soils of other taxonomic units and have only limited extensions.

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